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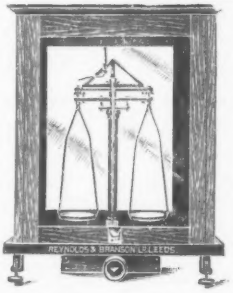

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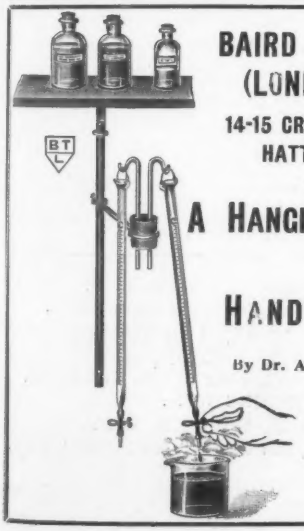

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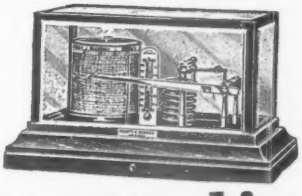

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Government Publications and their Distribution.

WHEN a government takes in its own hands the publication of matters of scientific interest, it may be assumed that this is done with three distinct objects in view. In the first place, it wishes to bring to the notice of scientific workers the results of original researches carried out by experts in Departments under its control, in order that these results may form a foundation for further advance in knowledge. So are published the papers comprised in the excellent scientific reports of the Ministry of Agriculture and Fisheries in England, and of the Fishery Board for Scotland. Or it desires to bring to the notice of the public, for the sake of the individual and through him of the nation at large, the condensed wisdom of science as bearing upon matters of practical importance. Such is embodied in the pamphlets and leaflets dealing with agricultural pests and plant diseases, with methods of land-cultivation and stock-raising, issued by the Ministry of Agriculture and Fisheries and the Board of Agriculture for Scotland. Sometimes these two aims are seen to run side by side, as in the Journals of Agriculture published both by the English Ministry and Scottish Board, in which matters of both scientific and practical interest appear.

The third object is very different from either of the above, its end being to inform the outside world, scientific and non-scientific, regarding the activities of institutions in which a general interest is taken; it takes its typical form in the annual reports of such establishments as the British Museum, the Natural History Museum, and the Royal Scottish Museum. This last object may seem to have little of scientific value to commend it, but it is in reality of prime importance; for institutions of the kind mentioned depend for many of their most valuable acquisitions upon the generosity of the public, and unless public interest is stimulated by full knowledge of progress and requirements, the national collections, and science, must in the end suffer.

The duty of scientific publisher assumed by the Government does not end, however, with the printing of pamphlets, nor are its aims thus attained; the question of distribution is second only to that of printing, and it is to this that we wish particularly to direct attention. Every scientific worker is aware of the generous and even lavish free distribution of scientific publications carried out by Government Departments of the United States of America; and one is tempted to speculate whether the activity and originality of research now apparent there may not be due in part to this sustained appeal to the scientific mind.

At no time could H.M. Government have been charged with a lavish or even generous distribution of the scientific fruits its workers have culled. It now appears that even the meagre distribution of former years is to be curtailed, and a false notion of economy threatens practically to abolish the free circulation of government publications of scientific interest. The new policy affects the three types of publications already mentioned in various ways.

In recent years, the annual reports of the Museums have dwindled until they have become dry skeletons, scarcely worthy of distribution, and quite unworthy of the great national institutions they represent. Compare them with the beautifully printed and illustrated reports of the American State Museums. Surely this is not the way to encourage the free giving of the public, on which the American Museums and our own so largely depend.

The leaflets of the English and Scottish Departments of Agriculture were formerly sent gratis on publication, from a standing list, to gardeners, farmers, and others interested in the checkmating of pests or the improvement of cultivation, and the wide distribution of these concise and generally up-to-date publications played a great part in combating local pests, and possibly in preventing the local pest from becoming a national pestilence. Now, to be received free each leaflet must be applied for in writing, and only one copy of any one leaflet is supplied gratis: the free circulation as a matter of routine has ceased.

As regards research publications, the position is no less serious. Here also free distribution to workers interested in like fields has ceased, and scientific societies no longer receive copies in exchange for their own publications. Yet, curiously enough, the scientific worker in foreign countries is to be given a preference denied to his British colleague, for foreign societies making exchanges are not to be placed under the ban.

A still further restriction has been brought into force. The circulation of the records of scientific discovery has always been greatly aided through the strictly discriminate distribution, by the discoverer himself, of author's separates; and most scientific journals are still willing to present an author with twenty-five copies or so of an original contribution. But personal application to government scientific workers for a particular separate has disclosed the fact that, at any rate in certain important scientific departments, the allowance of author's reprints granted by Government is limited to *three* copies, though indeed if the published price of the pamphlet be less than one shilling he may have six. A joint author, provided he has contributed more than a third of the research, is entitled to one-third of this normal allowance. Could cheese-paring be more ridiculous?

It would seem that, in the desire to save a mite, the Government is in danger of losing a mountain. The cost of a relatively small number of off-prints, once the type has been set up, can scarcely be compared with the gain likely to accrue from a wide circulation of scientific matter of practical and economic importance; and in this respect the Government has duties to the public and the scientific world other than those of a publisher controlling a purely commercial undertaking. As the matter stands, government researches will continue to be made, and the results laboriously gained by trained and expert workers will be printed at very considerable cost—and then consigned to oblivion in the cold storage chambers of H.M. Stationery Office or some other department.

There is no suggestion here that the Government should undertake wasteful distribution. It has always seemed to us unnecessary that when an allotment-holder applied for agricultural leaflets, having in mind garden pests, he should receive also instruction in pig- and poultry-keeping, in the values of farm manures, or in the financial affairs of agricultural co-operative societies. But this danger might be avoided by, let us say, grouping the leaflets for free distribution in distinctive and homogeneous sections for particular classes of inquirers, rather than by the drastic step of abandoning altogether the method of free routine distribution. Perhaps, short of the generous distribution of scientific papers with which the United States have made us familiar, something might be done by the wide circulation of the periodical H.M. Stationery Office lists of Government publications, from which scientific societies or interested individuals might select and apply for such works as concerned their own field of activity.

In any event, the distribution of Government publications dealing with matters of scientific interest cannot remain as it stands at present; it is based upon a narrow idea of the importance of the spread of scientific knowledge, even upon a mistaken computation of the pecuniary value of science. How diametrically opposed it is to the trend of enlightened opinion in Great Britain is indicated by a recent decision of the Carnegie United Kingdom Trustees to increase still further their free circulation of expensive books to whatsoever individuals care to take up any serious study. What is wanted is not less facilities for making scientific knowledge and achievement widely known, but more. It is to be hoped that scientific societies will not permit the recent restrictions to pass unchallenged, and will unite to secure for the public and for scientific workers the fullest publicity for information of service to them as stimulus or as guidance.

The Physiology of Sex-Determination.

The Mechanism and Physiology of Sex Determination. By Richard Goldschmidt. Translated by Prof. William J. Dakin. Pp. ix + 259. (London: Methuen and Co., Ltd., 1923.) 21*s.* net.

PROF. GOLDSCHMIDT gives us an object-lesson in the way in which a single problem, at the outset not apparently more important than a thousand others, may, if pursued to its limit, be made to yield results of the deepest importance and the widest application.

It has long been known to entomologists that crosses between different species, and often also races, of Lepidoptera frequently produce a number of sexually abnormal forms. This was the starting-point of the investigation which has finally enabled Goldschmidt to make his important contribution to the study of sex-determination, and indeed to the problems of differentiation in general.

Put in the briefest possible way, we may sum up the results of his twelve years of work upon the sexual abnormalities arising in racial crosses of the Gipsy moth (*Lymantria dispar*) as follows. In the first place, since moths have two active sex-(X-)chromosomes in the male, and one in the female, the male-determining factors are in double dose in males, single dose in females. The female-determining factor Goldschmidt has finally located in the Y chromosome—an interesting fact, since the work of the Morgan school on Drosophila has shown that there the Y chromosome is without influence upon sex-determination. He has next shown that the strength or "potency" of the sex-determining factors may vary, and does actually do so in the different subspecies and races employed. It follows that when a cross is made, the future distribution of the sex-factors of various strengths, both male- and female-determining, can be prophesied from what we know of the behaviour of the chromosomes, or, in other words, on Neo-Mendelian principles.

As to the mode of action of the female-determining factor, we have the important fact that the Y must exert its effect upon the growing oocyte, since we find that the female-determining factor (which is inherited purely maternally according to expectation) is effectively present in males as well as females, although, of course, in all eggs destined to give males the Y has been eliminated in the polar body. If we are to draw conclusions, it appears that some substance, which Goldschmidt considers as of enzymatic nature, is given off into the oocyte in quantity proportional to the "potency" of the female-determining factor in the Y, and exerts effects in embryonic development proportional to its quantity. It is clear that if this is fully substantiated, it gives us important clues as to the possible mode of action of chromosomal genes.

By these last facts we are introduced to the second part of the problem—the mode of action of the sex-factors during development in contradistinction to their distribution to the gametes and zygotes—a field where Goldschmidt has made his most signal contribution. What do we start with?—the presence in every male moth of two doses of male-determining, and one dose of female-determining substance; whereas in the female, to the same quantity of female-determiner there is only one dose of male-determiner. But, since normally, in spite of the presence in individuals of either sex of determiners for both sexes, we get only the two classes male and female, we must say that (using the symbols M and F for our two sex-determiners) $2M > F$, whereas $F > M$.

When different races were crossed, abnormalities were produced. Goldschmidt was, in the first place, able to demonstrate that, whatever the degree of abnormality (and all degrees are possible), they fell into two classes, those which started their development as females but ended it as males, and those which started it as males and ended it as females. They thus have no kinship with the other main type of sexual abnormality known in insects, in which one half (or some definite section) of the body is of one sex, the other of the other. These latter animals are thus sex-mosaics in space, whereas Goldschmidt's are sex-mosaics in time. The term *gynandromorphs* should be restricted to the spatial type, the term *intersex*, or better *consecutive intersex*, being used for the other. The origin of gynandromorphs is to be sought in an abnormality of mitosis whereby an X chromosome is lost from one embryonic nucleus, whereas that of the intersex is to be looked for in the faulty balance of sex-factors.

It is only in certain crosses that intersexuality appears. An analysis of the families, together with the above-mentioned discovery of the transformation of sex during development in the intersexes, led to the following far-reaching conclusions. Broadly speaking, most of the Japanese races of the species possess sex-factors of high potency, the European races of low potency. Intersexes result (1) when a high-potency or "strong" M (male-determiner) is combined with a "weak" F—in which case the result is a *female intersex*, or one which is genetically female and starts its development as a female, but is later switched over to maleness; or (2) when two weak M's are combined with a strong F, in which case *male intersexes* are found.

Further, within each main group, the separate races may differ in regard to the strength of their sex-factors;

and this will be reflected in the different *degrees* of intersexuality resulting from different crosses.

These facts, and various interesting consequences of the facts, may be regarded as firmly established. It should be noted that there are one or two local races which have given curious results, which will have to be worked out in greater detail.

Goldschmidt's further argument is as follows. The expressions "2M > F" and "F > M" express only the conditions in the fertilised eggs before development has started. The further facts can be explained only if we suppose that, during development, in each cell of the body sex-controlling substances are produced at definite rates, and that these rates are proportional to the original quantities of the sex-factors. When, for example, a strong M and a weak F are present together in an egg, not only is the difference F – M abnormally small, but the rate of increase of F or of substances produced by it is lower, that of M higher, than usual. As a result, the two curves eventually intersect; and, of course, from this moment the individual, hitherto female, is switched over to the male type of development, and a female intersex is the result. The degree of abnormality is of course determined by the relative rates of F- and M-production, and the consequent earlier or later incidence of the intersection-point in the life-history.

If the intersection-point comes early enough, and the change to the "wrong" sex occurs before any chitinisation has taken place, sex-reversal will be apparently complete, and we shall get nothing but one sex from our cross. This does occur.

Let us suppose the sex-reversal is from female to male. Then, in the resultant all-male broods, half the individuals should be genetically females, and therefore be of chromosome-constitution XY instead of XX. If mated with normal females, therefore, they should give an abnormal sex-ratio (2XY = ♀♀ : 1XX = ♂ : 1YY —dies), as was pointed out in general terms by Morgan and by the reviewer some time ago. Similar sex-reversal followed by abnormal sex-ratio in the next generation has since been shown to occur by two independent workers in the frog, and now Goldschmidt has rung the changes upon it in Lymantria and has shown that in every case the results fit with expectation. Thus the final *somatic sex* may be the opposite of the original *zygotic sex*.

But we can go even further than that. The reversal (total or partial) of the original sex may be due either to genetic or to other factors. In Goldschmidt's moths the reversal is due to genetic causes—the fertilised egg contained inevitably within itself the seeds of its eventual change of sex, in the form of a quantitative disharmony of the sex-determining factors.

But sex may be upset by outer agencies: by hormones, in the case of vertebrates, whether the experiment be of Nature's (as in the Free-martin, the female intersex of cattle, owing its abnormality to the male hormones of its own twin brother), or of man's (as in the remarkable castration and grafting experiments of Steinach, Sand, Moore, Lipschütz, Goodale, and others); by parasites, as in crabs and insects; or by interference with the gametes, as in the increased number of males produced in frogs (Hertwig and his pupils) or trout (Mrsic) by over-ripeness of the ova.

The earlier rigid belief that sex-determination was entirely a matter of the chromosome-constitution must therefore be modified. Sex, in all higher animals and in some plants, is *normally* determined by the chromosomes, but (as might have been foreseen) the normal agency can in certain circumstances be overridden.

It is clear that, with the point of view arising from these facts, much that is both new and important has been gained. In the first place, we have the confirmation of the idea, which had become established as a result of the work on Drosophila, especially by Bridges, that sex-determination was an affair of balance between genes contained in the sex-chromosomes and other genes.

Bridges, by the utilisation of triploid strains, showed that in the fly, while the female-determiner was mainly lodged in the X (since here the female is XX, the male XY), male-determination was not an affair of one but of several factors, a disproportionate amount of influence being entrusted to that or those in the diminutive 4th chromosome. Two X's in the presence of three sets of autosomes gave intersexes: if only two instead of three of the 4th chromosomes were present, the intersexes were of more female type. We do not profess to understand Goldschmidt's comments (p. 99):—"... instead of speaking of the different quantities of a sex factor he [Bridges] prefers to speak of a more or less greater number of factors. Logically as well as physiologically this is naturally the same."

Although Goldschmidt has shown that his "F" substance is largely due to factors lodged in the Y chromosome, yet it may be confidently predicted that numerous "sex-modifiers" will be discovered in the autosomes.

Our second principle is concerned with development. Goldschmidt's idea of different rates of production of substances in the embryo is in itself very fruitful, while if his correlation of the rate of production of the substance with the amount of some initial ferment contained in the gene, and this amount with the "potency" of an allelomorph in a multiple series,—if this is substantiated, we acquire a new outlook into the relation between Mendelian genes and their mode of action in development.

That a correlation of some sort does exist between rate of developmental processes and nature of gene appears to be established; but whether there exists the exact chain of events imagined by Goldschmidt is a matter for further verification.

How valuable is the conception of rate of production of substances in ontogeny is seen by the rapid application which it has found in other fields. Crew has applied this idea to the explanation of various puzzling abnormalities of the reproductive organs to be found in mammals, and by so doing has removed them from the lumber-room where they lay labelled with the meaningless title of "pseudo-hermaphroditism" to a place in a coherent biological scheme. It appears more than probable that the determining factor in Amphibian metamorphosis, with all its curious variations from species to species, is simply the relative rate of thyroid growth. It will assuredly prove that the same concept will be of prime importance as regards the other endocrine glands in all their functions of growth-regulation and of initiating new phases such as puberty. In brief, the ideas of physical chemistry are thus being introduced into embryology, and dynamic ways of thinking substituted for static.

So much for the important positive results, both of fact and theory, which flow from Goldschmidt's work. It remains to criticise some of his details.

We think it right in the first place to emphasise the fact that the well-known curves illustrating the physiology of intersex production (p. 95) are quite hypothetical in their details—a fact not sufficiently brought out in the text. They could be drawn in a considerable number of quite other ways and still satisfy the facts. In particular, this applies to the representation of the curve for production of "female" substance as rising to a maximum and then sinking again. This is of great theoretical importance if really true; but no adequate discussion is given of the reasons for the adoption of this particular curve, nor for the rejection of, *e.g.*, a curve which continued to rise throughout life.

The same, *mutatis mutandis*, is true of various other of the curves presented later for other organisms—although here their hypothetical nature is made clearer. We think that in many cases it would have been equally easy to employ the idea of alteration in susceptibility of tissues to a constant stimulus (as exemplified, *e.g.* in the alteration in susceptibility of Anuran limbs to thyroid at metamorphosis) instead of that of alteration in the amount of morphogenetic substance (intensity of stimulus).

We note the absence of reference to Haldane's interesting work (in reality a corollary of Goldschmidt's own principles) that when one sex is reduced in numbers or abnormal in structure as a result of a varietal or specific cross, it is—not always the male or always the female, but—always the heterogametic; and also wonder why play is not made (pp. 222-224) with the idea that sex-linked semi-lethal factors account for the well-known differential elimination of males before and soon after birth in man and other mammals—an idea which at least gives full formal explanation of otherwise incomprehensible facts.

In his discussion of human sexual abnormalities (p. 243) the author has only been thinking in terms of his previous Lymantria scheme, which will give greater or lesser sex-transformation as a result of faulty balance of sex-genes: Crew's recent papers on goat and pig intersexuality suggest another and simpler explanation, in the idea of abnormally slow production of the male hormone, but without any switch-over from one sex to the other. No reference is made to the classical work of Pézard on birds, in which the effect of the gonad hormones upon growth-rate of sexual characters is so ably analysed.

These, however, are matters of comparatively minor moment. The main thesis of the book stands, and is of great value. In addition, various subsidiary topics are discussed with great lucidity. We especially commend the section on secondary sexual characters. The treatment is not new, but so clear and incisive that after reading it there should be no excuse for the not uncommon misconception that the inheritance of such characters throws any light upon or is in any way correlated with the inheritance of sex itself, save only that once sex is determined, it controls the *expression* of one or the other set of secondary characters.

The well-known difference between the physiology of sex-determination in insects and vertebrates—in the former independent of all gonadial influence, in the latter put under this influence from a very early period of ontogeny—the author correlates with the general shortness of life in insects as against its greater length in the higher group. This is an extremely suggestive idea; it will be interesting to see whether subsequent research upon the connexion of gonad and sexual characters in other invertebrates will bear it out. Finally, after the mass of nonsense and vague theorising that has been written on the sex-ratio, we commend his chapter on the subject as an admirable tonic.

It has seemed worth while to go into some detail regarding the thesis and scope of the book, in spite of its having been first published in German three years ago, since here for the first time are English readers provided with a translation (which, since Goldschmidt has incorporated recent work, is also a second edition). The book is intended for medical men and others, such as lawyers or sociologists, who may have occasion to study the problems of sex, as well as for the professional

biologist, and it is a fact, however unfortunate, that the great majority will not read a foreign language unless they must. The translation is direct and adequate, and reads smoothly, although a few Germanisms might be got rid of in a second edition.

Work on the problems of sex is proceeding so rapidly that Doncaster's and Morgan's books on the subject, although not ten years old, are quite out-of-date. We have no hesitation in recommending Goldschmidt's work as the best existing introduction to the subject, and tendering our thanks to Prof. Dakin for his translation.

JULIAN S. HUXLEY.

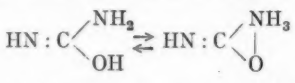
Chemistry of Urea and Resins.

(1) *The Chemistry of Urea: The Theory of its Constitution, and of the Origin and Mode of its Formation in Living Organisms.* By Prof. Emil A. Werner. (Monographs on Biochemistry.) Pp. xii+212. (London: Longmans, Green and Co., 1923.) 14*s.* net.

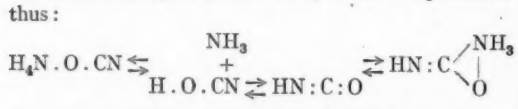
(2) *Synthetic Resins and their Plastics.* By Carelton Ellis. Pp. 514. (New York: The Chemical Catalog Co. Inc., 1923.) 6 dollars.

(1) THE monograph on urea differs somewhat in scope from others of this series of which it forms a part, inasmuch as it deals almost exclusively with one compound. Its importance, however, in animal and vegetable life is unquestioned, and no one will feel that a whole volume devoted to this topic is an unnecessary addition to biochemical literature. The subject-matter is divided into two sections: the first treats of the synthesis and constitution of urea; the second with its origin and occurrence in Nature.

There is no one more competent to write on urea than the author, who for many years past has attempted to unravel its structure. A considerable portion of the first section is concerned with this problem, and it must be confessed that Prof. Werner has made out a strong case for the tautomeric formula



There is no doubt that the majority of changes which urea undergoes with different reagents and by heating, such as the formation of biuret, and the conversion of ammonium cyanate into urea, which is represented thus:



may be equally well explained by the new formula. Moreover, the formation of cyanuric acid and the action of alkalis receive a much simpler interpretation in this way.

(2) As a rule, an organic chemist, when confronted in the course of an investigation with a resinous product, is discouraged from examining it further. It is an amorphous, intractable material which generally defies crystallisation and, consequently, the only satisfactory means of purification. It is therefore consigned to the scrap heap. The technical chemist, on the other hand, whose business it is to manufacture varnishes and composite materials, such as printing-inks, paper and cloth size, linoleum, etc., far from despising such products, is able to utilise many so-called synthetic resins on a very considerable scale. The volume under review gives a very comprehensive account not only of the production and use of synthetic resins; but also a detailed description of the machinery used in their application. He tells us that "the diminishing supply of natural resins, or *gums*, as the trade prefers to call them, has been viewed with apprehension during past years by varnish manufacturers and other large consumers of such products."

It appears that the introduction of phenol-formaldehyde and cumarone resins has opened up a new field for the synthetic organic chemist. There is a remarkable variety of substances now employed and derived from such products as glycerin and phthalic acid, vinyl polymerisation products, urea and thiourea derivatives and sulphur phenol resins. The author advises the chemist to scrutinise carefully every new resin he may obtain and record its formation. Here is a new and interesting field of operations, and instead of feeling thwarted in his aim, the organic chemist may in future turn what he formerly regarded as a failure into a possibly lucrative success. J. B. C.

Micrography as a Fine Art.

Botanical Pen-Portraits. By Prof. J. W. Moll and Dr H. H. Janssonius. Pp. viii+472. (The Hague: Martinus Nijhoff, 1923.) 30 guilders.

IT was not until about the middle of the nineteenth century that descriptions of microscopical characters were introduced into treatises concerned with the identification of drugs. There are now several books primarily designed for students of pharmacy, but occasionally referred to by botanists who endeavour to demonstrate to their students that even a knowledge of plant histology may have its economic value. The volume by Prof. Moll and his junior collaborator aims at giving greater precision to the description of vegetable drugs and therefore greater accuracy in their identification.

Prof. Moll has devoted himself during the last twenty

years to a subject which demands no little concentration of effort and an enthusiasm that is proof against the dullness of tedious routine; he has devised a method of scientific description which he believes to be an advance upon all previous systems. The technical value of this method can only be thoroughly tested by specialists, but a mere botanist can at least appreciate the soundness of the underlying principles and the meticulous attention to details. The author is to be congratulated on the successful completion of a labour of love which is a contribution of great value to the pharmacologist and to all botanists whose aim is to acquire an orderly and thoroughly sound method of describing plant structures.

An adequate description of a plant must take account not only of the characters in which it differs from allied types, but also of those which it shares with other plants. Pen-portraits aim at furnishing a summation of characters, the replacement of sketches of habit by clear descriptions based on a definite scheme which is given in full and constitutes a very important feature of the book. They do not rely upon detailed anatomical drawings to supplement imperfect descriptions: a pen-portrait, if thoroughly made, is self-sufficient and at most needs only a well-labelled diagrammatic representation of the plant organ under consideration; it brings into the description "as much as possible of what is now generally considered as belonging to the domain of drawings and plastic models, in other words, it tends to make pictures more and more superfluous." The diagrammatic illustrations are exceedingly clear, and of a kind which might with advantage be adopted as a model by authors of botanical text-books.

The value of Prof. Moll's method was demonstrated by the junior author, Dr. Janssonius, in his book, published in 1906, on the micrography of Javan trees: an extension of the same method to timber trees of other regions would be a great boon to botanists, especially to such as are interested in the identification of fossil angiospermous woods.

The preface, which is much more than a preface in the ordinary sense, gives a clear account of the history of descriptive botany, with special reference to microscopical features, and emphasises the importance of a more definite employment of the Linnean method in micrography. Prof. Moll considers that the principal feature of the Linnean method is its conformity to a sequence fixed beforehand; if it is rigorously followed, completeness is achieved and nothing is omitted by chance. A high standard is set, and the "guiding schemes," if the student has sufficient faith and patience to adopt them, supply the means of constructing pen-portraits according to the admirable patterns contained in this great work. Most of the volume is devoted to descriptions of drugs arranged in alphabetical order—Amylum, Cortex, Flores, Folia, Fructus, etc.—and a full bibliography is added. In illustration of the method, the headings of the section dealing with Cortex Cinnamomi may be given: macroscopic characters; anatomical characters, followed by a list of references; epidermis, including measurements of cells; cortex, cork, phellogen, phelloderm; primary cortex; endodermis; stele, including detailed description and cell-contents of the tissues; micrography of the powder, bast fibres and other cells, crystals, starch grains, etc. A word of praise is due to the publishers for the printing and style of the book, and to the authors for their decision to present their work in well-written English. A. C. SEWARD.

Our Bookshelf.

Text-book of Agricultural Bacteriology. By Dr. F. Löhnis and Prof. E. B. Fred. (Agricultural and Biological Publications.) Pp. ix+283+10 plates. (New York and London: McGraw-Hill Book Co. Inc., 1923.) 15s.

DR. LÖHNIS' "Vorlesung über landwirtschaftlicher Bakteriologie" has for so long been regarded as an essential text-book, that students of agricultural bacteriology will especially welcome the excellent English edition of this work which the author has produced in collaboration with Prof. E. B. Fred.

The authors devote the first portion of their work to a description of the characteristics and general activities of micro-organisms. This part of the book contains useful chapters in which the general methods used in studying the organisms are discussed. The second half of the book is devoted to the special fields of bacteriology that touch upon the problems of agricultural research and practice. There are chapters on the bacteriology of silage, hay, and other food materials, on milk, butter, and cheese, on the methods of sewage disposal, on the changes involved in the making of farmyard manure and on the problems of soil biology. In these chapters the authors deal with their subjects with remarkable clearness. The very different problems that arise in these fields of work make it very difficult to connect them as though they formed a single branch of applied science. It seems that the sequence of thought would have been better preserved in this portion of the book if the bacteriology of soil had been considered before that of dairy products, because, in the former subject, the problems involved so completely cover the field of microbiology, that the authors have already been obliged to refer to the chief groups of soil bacteria to illustrate the activities of bacteria in general. In dealing with the bacteriology of soil and of dairy products, the authors discuss some of the special methods used in these fields of work. In a later edition, the description of special methods might well be given in greater detail. At present, lack of standardisation in technique greatly hinders work with bacteria, and this is especially the case with soil and dairy bacteriology. A detailed description of the best

methods, given in such a well-known text-book, would greatly assist the adoption of a uniform technique.

In the portion of the book devoted to soil bacteria, the activities of protozoa and other micro-organisms are mentioned, but greater emphasis should have been given to the close interrelation that exists between bacteria and other organisms in the soil. The close connexion found to exist in field soil between the rapidly changing numbers of bacteria and active amœbæ illustrates the fact that the bacteria must be considered as a part of the complex population of the soil. H. G. THORNTON.

Mine Examination Questions and Answers. Compiled from Examinations for Positions of Mine Inspector, Mine Foreman, Assistant Foreman, Fireboss, Hoisting Engineer, Safety Inspector and Shotfirer. By Prof. J. T. Beard. Part 1. Pp. viii+258. Part 2. Pp. vi+259–546. Part 3. Pp. vi+547–872. (New York and London: McGraw-Hill Book Co. Inc., 1923.) 3 parts, 37*s.* 6*d.*

THE object of the work under notice is, as stated by the author in his preface, that of "enabling candidates to pass successful examinations for positions of responsibility in coal mining," and it consists of a set of answers to no less than 2975 questions, set in examinations in the various coal-mining states of the United States of America and in Canada for various grades of colliery officials. Opinions will certainly differ as to whether this is the best way of qualifying a man for the duties that he will have to perform after he has passed such examination; it may readily be granted that a man, gifted with an exceptional memory, might get off by rote the whole of the answers to the questions given in these three volumes and would thus with ordinary luck pass successfully any of the examinations referred to, but it is also very certain that this fact would not qualify him to hold a position as a responsible underground official. The educational value of such a book is therefore very questionable. At the same time the work has been well done. Prof. Beard has been the Principal of the School of Mines, International Correspondence Schools, Scranton, Pa., Secretary to the State Board of Mining Examiners, Iowa, and has held many other positions that qualify him thoroughly for the work that he has undertaken, and his book may be used with every confidence in its accuracy. It must, however, be borne in mind that coal mining methods, legislation, and nomenclature are so different in the United States from what they are in Great Britain that many of the answers given would prove seriously misleading to British candidates for similar positions in the latter country.

The Properties of Matter. By Prof. Basil C. McEwen. Pp. vi+316. (London: Longmans, Green and Co., 1923.) 10*s.* 6*d.* net.

As a text-book, this work differs from its predecessors in the order of treatment of the subjects. Commencing with the First Law of Thermodynamics and the more general Principle of the Conservation of Energy, a logical sequence leads to the study of the kinetic theory of matter, which is most easily treated in connexion with the gaseous state. The continuity of the gaseous and liquid states supplies the natural transition to a detailed study of liquids, and solids are dealt with last of all. The reviewer can recommend this order from his own experience in lecturing to university students, and is of the opinion that the first half of Prof. McEwen's book reaches a high standard of excellence. Some parts of the latter half are not quite so satisfactory. The chapter on capillarity seems somewhat elementary and does not contain many references to modern work. The distinction between surface tension and surface energy is not well brought out. The chapter on solids is very short, and should be greatly expanded when a new edition is called for. We hope the author will then include an account of the crystalline structure of solids as revealed by X-ray analysis. H. S. A.

Medical Climatology of England and Wales. By Dr. E. Hawkins. Pp. xiv+302+149 charts. (London: H. K. Lewis and Co., Ltd., 1923.) 25*s.* net.

EVERY practitioner of medicine is frequently required to recommend a climate suitable for convalescence or for a chronic disease; few doctors can acquire from experience the geographical and meteorological knowledge to enable them to give adequate consideration to this important detail of treatment. Dr. Edgar Hawkins provides a volume on the subject, based on his own experience and the information derived from numerous meteorological publications. The main arrangement of the book is geographical, therapeutic indications following the descriptions of the geology and climate of various districts and towns. There is also a separate chapter on therapeutics of the English climate, in which the classification is based on diseases. In one appendix the health resorts are tabulated according to seasonal suitability, and in the other the waters of the various Spas are described.

In spite of the complexity of the subject, information with regard to locality or disease can readily be found, and reference is facilitated by the inclusion of a large number of meteorological charts and the addition of a well-prepared index. The book will be of considerable value to physicians and others interested in medical climatology.

The Elements of Co-ordinate Geometry. By S. L. Loney. Part 2: *Trilinear Co-ordinates, etc.* Pp. viii+228. (London: Macmillan and Co., Ltd., 1923.) 6*s.*

THIS part of Prof. Loney's "Co-ordinate Geometry" contains, in order, chapters on cross-ratio geometry, trilinear and areal co-ordinates, tangential equations, reciprocation, projection, and invariants of conics. Methods of teaching geometry have advanced considerably in the last twenty years, and the arrangement adopted by Prof. Loney would scarcely be accepted as the natural one now. Trilinear and areal co-ordinates are here introduced from the purely metrical point of view. Now it would be more customary to read the chapters on projection and reciprocation first and then to treat trilinears and areals as particular cases of homogeneous co-ordinates.

Coming from an experienced teacher of mathematics, the book gives all necessary assistance to a student reading its subject-matter for the first time in the order treated. Abundant examples are given, but those on homogeneous co-ordinates include a greater proportion of metrical questions than a present-day teacher would endorse (*e.g.* pp. 85-87, Nos. 1, 2, 6, 7, 16, 17, 20, 22, 23, 24).

Letters to the Editor.

The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, nor to correspond with the writers of, rejected manuscripts intended for this or any other part of NATURE. *No notice is taken of anonymous communications.*]

The Gorilla's Foot.

WITH regard to Mr. Akeley's cast of a gorilla foot discussed in NATURE of November 24, p. 758, I note that Sir Ray Lankester did not wait until he had seen the cast which we sent to the British Museum (Natural History) but has again made the following charges:—(1) The picture of the cast of the foot in Mr. Akeley's book "In Brightest Africa," p. 242, gave a misleading or distorted view of the cast and was in effect an example of bad photography. (2) The gorilla foot as represented by the cast differed in appearance from all previous pictures of and statements about the gorilla's foot and was misleading, chiefly because it did not show the great toe in a divergent position; it also differed in appearance from the photograph of another gorilla's foot figured by Akeley in the same book (p. 231), in which the great toe was shown in the flexed and abducted position. (3) Therefore Akeley had himself supplied the refutation of his claim that his gorilla's foot was different from any other yet discovered. (4) That it is "highly improbable" that Akeley's photograph of the cast "correctly represents the foot of a normal species or variety of gorilla."

As to (1), I have already stated (NATURE, November 24) that the photograph published in Mr. Akeley's book gave a "very fair" view of the cast in question, and after a careful re-examination of the facts I will add nothing to that statement except that Mr. Akeley has a deservedly high reputation based upon many years of experience both in photographing and in making anatomical casts, and needs no warning from any one as to the precautions to be observed in such work.

As to (2), neither Mr. Akeley nor I ever asserted that the cast in question showed the hallux in the position that it probably assumed when the animal's weight rested upon it. I quoted Mr. Akeley's statement that the cast was taken in the relaxed condition of the foot after *rigor mortis* had passed away, and I also noted that the hallux could no doubt be more or less abducted. The cast was made within twenty-four hours after death, in a cool, moist climate. The foot was cut off from the leg, the muscles and ligaments being relaxed, and was placed in a hollow in the ground with the sole facing upward. The foot and its digits were not posed but were allowed to assume the relaxed position. After being lightly soaped a thin coating of plaster was then applied and allowed to set, in order to prevent distortion by the weight of the plaster. No other outside pressure was exerted in any direction when the plaster was poured around. The whole operation was conducted with exceptional care to avoid distortion.

The outstanding feature of Mr. Akeley's cast is that it shows that in the relaxed condition the hallux assumed a position of lesser divergence, so that it was more nearly in line with the other digits. In this connexion it is pertinent to state that Dr. D. J. Morton is now studying the anatomy of the foot of another one of Mr. Akeley's adult gorillas, and finds that the arrangements of the internal cuneiform and first metatarsal bones are such that it is possible for the hallux to be drawn into the position shown in Mr. Akeley's cast. Dr. Morton has also found that in Mr. Akeley's, as well as in other adult specimens, the distal ends of the metatarsals of all the digits are twisted upon the shafts at different degrees in such a way as to make the volar surfaces face more directly downward, whereas in infant gorillas the volar surface of the hallux is tilted toward that of the other digits, this arrangement being still more pronounced in the chimpanzee. After extensive comparison, Morton concludes that the infant gorilla foot retains more of the primitive arboreal characteristics, while the adult gorilla foot shows numerous man-like adaptations not found in the chimpanzee.

As to (3), Mr. Akeley never claimed that his gorilla's feet were different from all others previously described. Such may yet prove to be the case in regard to the detailed proportions and minor characters of the foot, but it has not yet been asserted by either Mr. Akeley or myself.

As to (4), the original foot from which the cast was made has not yet been compared minutely with the other gorilla feet collected in the same general region, but after a preliminary comparison there seems no reason to brand the individual as representing an "abnormal species or variety."

In brief, Mr. Akeley's cast can be misleading only to those who read into it more than was claimed for it, or who do not realise that a gorilla's hallux may assume a position other than that figured in the previous literature of the subject. A carefully made cast of this kind is of greater scientific value than any photograph of the same object, because it represents the object in the round and without photographic distortion. A good cast, such as this unquestionably is, gives indisputable evidence of fact.

In conclusion, Sir Ray Lankester's statements in his book, "Great and Small Things," about the significance of the differences between human and anthropoid feet, suggest that he is one of several eminent persons (including Mr. H. G. Wells) who do not see that the human foot is an anatomical palimpsest, in which the later record of a long terrestrial life is so deeply impressed that it has largely obscured the underlying older record of a previous arboreal stage with a divergent hallux. This is not a "theory" but a well-founded inference from the many facts that are now being examined by Sir Arthur Keith, Dr. Morton, and others.

WILLIAM K. GREGORY.
American Museum of Natural History,
New York, December 7.

Psycho-Analysis and Anthropology.

REFERRING to the letters in NATURE from Dr. Malinowski (November 3) and Prof. Elliot Smith (November 24) on this subject, I should like to make three remarks.

(1) While agreeing with all that Prof. Elliot Smith says as to "Totem and Taboo," and that Freud failed to acquaint himself with the essential facts and associations of which he writes, this is by no means the case with all of his disciples, while even in "Totem and Taboo" there is stress laid on the quality of ambivalence in savage belief and custom, which, if I judge rightly, had not previously been sufficiently appreciated by anthropologists. It may be that Prof. Elliot Smith has recognised this in his article in the *Monist*, which I have not had the opportunity of reading.

(2) I rather doubt whether time will bear out Prof. Elliot Smith's contempt for typical symbols. Type dreams—that is, identical dreams having the same meaning attributed to them—certainly occur among peoples genetically and culturally remote. Thus, to take an example, quite superficial reading, and the kindness of friends in supplying references, indicates

that the tooth-losing dream occurs in Europe and among Nagas, Malays, and Chinese, also Ashanti, and that in each case it is taken to mean the death of a near relative (Ashanti, loss of near friend). Moreover, this meaning fits well with the individual significance commonly recognised by analysts, namely, the fear of castration.

(3) The question of "Universal Symbolism" is of course the crux of the whole matter. Are the findings of analysis for the individual applicable to the social unit to which he belongs; and if so, do they also apply to other groups which may be genetically remote?

Those interested should shortly have the opportunity of hearing the problem examined from the psycho-analytic point of view, for Dr. Ernest Jones has consented to read a paper upon this subject before the Royal Anthropological Institute on Tuesday, February 19. Tickets of admission will willingly be sent to non-members of the Institute interested in the subject, who should apply to the Assistant Secretary, Royal Anthropological Institute, 50 Great Russell Street, W.C.1. C. G. SELIGMAN.

Malaria and *Anopheles funestus* in Mauritius.

EARLY in 1922 I was asked by the Secretary of State for the Colonies to undertake an Anopheline and anti-malaria survey in the island of Mauritius. I accepted this mission, and had the pleasure of devoting ten months of intensive investigation to a survey of unusual interest.

Prior to my visit to Mauritius, a somewhat similar survey had been made in 1908 by Sir Ronald Ross, Major Fowler, and Mr. d'Emmerez de Charmoy. The valuable work they accomplished and the many interesting observations made by them are recorded in Ross's report entitled "Prevention of Malaria in Mauritius" (London, Waterlow and Sons, 1908).

In the course of their work, Ross, Fowler, and d'Emmerez de Charmoy made an extensive survey of the mosquitoes of Mauritius, which resulted in the collection of the following species:

OLD NOMENCLATURE.

1. *Myzorhynchus mauritianus*. Daruty de Grandpré & d'Emmerez de Charmoy.
2. *Myzomyia* (*Pyretophorus*) *costalis*. Theobald.
3. *Nyssorhynchus maculipalpis*. Giles.
4. *Scutomyia notoscripta*. Walker.
5. *Stegomyia fasciata*. Fabricius.
6. *Culex fatigans*. Weidemann.
7. *Culex tigripes*. Daruty de Grandpré & d'Emmerez de Charmoy.
8. [1] *Culex annuliorius*. ?
9. *Culex arboricolis*. d'Emmerez de Charmoy.
10. *Culex ronaldi*. d'Emmerez de Charmoy.
11. *Culex fowleri*. d'Emmerez de Charmoy.

MODERN NOMENCLATURE.

1. *Anopheles mauritianus*. Daruty de Grandpré & d'Emmerez de Charmoy. Very common.
2. *Anopheles costalis*. Theobald. Very common.
3. *Anopheles maculipalpis*. Giles. Very rare.
4. *Aëdes albopictus*. Skuse.
5. *Aëdes argenteus*. Poiret.
6. *Culex fatigans*. Fabricius.
7. *Lutzia tigripes*. Daruty de Grandpré & d'Emmerez de Charmoy.
8. [1] *Culex annuliorius*. ?
9. *Orthopodomyia arboricolis*. d'Emmerez de Charmoy.
10. *Culex sitiens*. Weidemann.
11. *Aëdes nigerensis*. Theobald.

[1] *Note.*—*Culex annuliorius* should not be listed among the mosquitoes of Mauritius, as the record is probably due to an error in identification.

It will be seen from this list that three species of Anophelinæ were found, and I have added the remarks made by these investigators relating to the prevalence of the Anopheline species.

By experimental work in Mauritius, Ross was able to prove that of the three Anophelines, *A. costalis* was easily infected with malaria and could be regarded as the chief vector; that *A. mauritianus* apparently could not be experimentally infected with malaria, and by much additional evidence could be regarded as incapable of malaria transmission; while, owing to the great rarity of *A. maculipalpis*, which these investigators state was then the case, there was no opportunity of obtaining *A. maculipalpis* in numbers sufficient for experimental work. Its presence in Mauritius was therefore considered of no practical importance at the time.

Based on these discoveries, Ross indicated the plan that should be adopted for the institution of an anti-malaria campaign in Mauritius. Unfortunately, his recommendations were not thoroughly carried out, and although much useful work was done by the canalisation of streams and the abolition of swamps in many parts of the island, the success of the campaign was vitiated by the neglect of equally important Anopheline breeding-places, and in many cases by allowing the completed anti-anopheline works to revert to natural conditions.

Consequently, fourteen years afterwards malaria in Mauritius was as bad as ever—a fact which, together with the totally insanitary state of the island, led the Governor, Sir Hesketh Bell, to decide to ask the Colonial Office to appoint an expert in tropical hygiene to visit the island and indicate the necessary measures for the correction of the many serious defects.

The Secretary of State for the Colonies called upon Dr. Andrew Balfour to undertake this mission, and Dr. Balfour left for Mauritius in February 1921. The utterly insanitary state of the island, and the very large number of separate problems with which Balfour had to contend, are fully set out in his comprehensive report, entitled "Report on the Medical and Sanitary Matters in Mauritius, 1921," published by the Colonial Office.

With regard to malaria in the island, Balfour speedily saw that, for renewed effort against the Anophelinæ, it was essential to know more of the bionomics of *Anopheles costalis*, the species then thought to be the only species responsible for the intensely malarious condition of Mauritius. His view was that it was highly important to know whether the species did or did not hibernate during the winter months, at least at the higher altitudes of the island, so that future work might take into account this most important fact.

On his return to England, Balfour recommended that investigations to determine the bionomics of *A. costalis* should be undertaken. I therefore left England for Mauritius early in 1922 to carry out this work.

For the first four months after my arrival in Mauritius (then the winter months), my staff and I gave undivided attention to the work of determining whether *Anopheles costalis* exhibited hibernation; and we were successful in showing that hibernation did not occur either at the coast or inland—a matter that is fully dealt with in my report to be published shortly by the Colonial Office.

During the work on *A. costalis*, much to my surprise I discovered that, in spite of what Ross had said in 1908, *Anopheles maculipalpis* was now to be found in very large numbers all round the island and up to an altitude of 1200 ft.

Later, with more time to devote to further studies

after *A. costalis* and the hibernation problem had been settled, my assistant and I while searching a marsh near Port Louis were astonished to find a larva of *A. funestus*. Further search in this marsh demonstrated that *A. funestus* was here in large numbers. The fact that *A. funestus* had not been recorded from Mauritius before, in spite of the work of the previous investigators, coupled with the proximity of the marsh to Port Louis—where all ships enter Mauritius—led me to assume that the species had only recently been imported. I immediately approached the Officer Administering the Government for authority and funds to abolish this marsh; and by the copious use of paraffin castor-oil mixture, while hundreds of men tore up the weeds, by drainage and filling-in operations, within a few days the marsh was changed into dry land.

Control of all the nearby waters—fortunately few—was instituted, and no larva appeared in these waters. A few days later, while I was in conversation with one of the chief moustiquiers (mosquito searchers)—an Indian who had been trained by Ross and Fowler—this man told me that he thought he remembered having seen similar larvæ while Ross was in the island, at Schonfeld Marsh, Riviere du Rempart in the north.

I questioned him further, pointing out that it was difficult to remember the appearance of larvæ after the lapse of 15 years; but he seemed so certain that I despatched him to Schonfeld to search. Schonfeld Marsh is rather inaccessible, some 15 miles from the marsh at Port Louis, and as the man had to go on foot it was two days later before he returned. When he got back, however, he brought with him six larvæ of *A. funestus*. My assistant and I at once left for Schonfeld Marsh in my motor-car, taking the man with us, and after searching for two hours in this extensive marsh, I discovered a larva of *A. funestus* there for myself.

On my return to Port Louis, I issued instructions that all moustiquiers should divide up and proceed to all parts of the island and search only for *A. funestus*. Two weeks later, *A. funestus* had been reported from practically every district of Mauritius, but the numbers found were surprisingly few.

I then decided personally to undertake the study of the bionomics of the species, and I at last found—as I have fully described in my report—that *A. funestus* existed in Mauritius in prodigious numbers, in some localities actually outnumbering *A. costalis*. The failure to discover the larvæ in numbers before was due to the fact that the vibrations transmitted through the earth by the tread of the searchers warn the larvæ of danger, and they all dart to the roots of the vegetation, to which they cling, *or even climb a few inches up the damp surfaces of the leaves* which dip into the water. Once this fact had been discovered, thousands of *A. funestus* larvæ could always be had in suitable breeding-places.

I undertook experiments in malaria transmission by *A. funestus* and *A. maculipalpis* in the island, and found that the former species could very easily be infected, and that *A. maculipalpis* could also be infected without much difficulty. Consequently, instead of *A. costalis* being the only vector of malaria in Mauritius, there are in reality three vectors: *A. costalis*, *A. funestus*, and *A. maculipalpis*.

Now, there are two theories to account for the malaria in Mauritius:

(1) That *A. costalis* (and *A. funestus* and *A. maculipalpis* ?) have existed in Mauritius for centuries, and that it was only the importation of large numbers of Indians to work in the sugar-cane industry, bringing with them in their blood the parasites of malaria, that caused the extensive infection of the local anophelines.

(2) That prior to 1865, when the first considerable outbreak of malaria (?) occurred, no anopheline vector existed in the island, and that it was only by accidental importation of *A. costalis* (*A. funestus* and *A. maculipalpis*?) then that Mauritius became malarious.

Personally I am inclined to favour the first theory, but the following experience shows how impossible it is to be dogmatic.

Towards the end of my work in Mauritius, hearing that the sister island of Rodrigues was free of malaria, I obtained sanction from the Officer Administering the Government to proceed to Rodrigues in order to investigate this report.

The island is so small that it was possible, with the assistance of three skilled helpers, to search all the streams, marshes, and pools. No Anopheles were to be found, and no case of malaria acquired in Rodrigues existed, although on the other hand I was able to find persons with all three species of the malaria plasmodia in their blood, which they had acquired by former residence in Mauritius.

The island of Rodrigues lies 365 miles to the east of Mauritius, and is visited regularly, though only every 3-4 months, by the Government supply steamer from Mauritius. On this ship, which is berthed in Port Louis, *A. costalis* was found even during my voyage, and it seems obvious that the only thing that accounts for the fact that Anophelines have not been introduced into Rodrigues is that the island is completely surrounded by an extensive and remarkable coral reef, running from 1½-6 miles seaward, which forces all vessels to anchor at least 1½ miles from shore. Moreover, a steady wind from the south almost invariably blows across the island from the shore across the anchorage.

In my report I have described these investigations at length, but I am in the meantime asking Sir Ronald Ross if he will be good enough to add any remarks he may care to make on what these investigations have shown.

MALCOLM E. MACGREGOR.

Wellcome Field Laboratory, Wisley, Surrey
(Wellcome Bureau of Scientific Research).

THESE investigations appear to me to be both theoretically and practically important. The question is whether *A. funestus* entered Mauritius after my visit in 1908. Major C. E. P. Fowler and myself were in the island from November 20, 1907, until February 25, 1908, that is, during the summer. Of course, we could not make anything like a complete survey of the mosquitoes in that time, but we were given the assistance of Mr. D'Emmerez de Charmoy, the accomplished entomologist of the island and curator of the museum, and were also provided with ten "moustiquiers," that is, trained mosquito men. Our principal investigations were made close to the Clairfond Marsh at Phœnix—which was drained in 1908; but Major Fowler and Mr. D'Emmerez investigated much further afield than this. It is therefore most surprising that we did not once come across *A. funestus*. I remember that when I first found *A. costalis* in the island I expected to discover *A. funestus* pretty shortly, partly because we had found them in association in Sierra Leone (where indeed we had discovered and named *A. funestus*), and also because we heard that both mosquitoes abounded in the neighbouring island of Madagascar. It seemed surprising to me that only one of these Madagascar Anopheles had managed to drift into Mauritius. Moreover, we heard that it

was absent from the island of Réunion, where *A. costalis* was present. I understand that Mr. MacGregor found *A. funestus* in numbers during the period of summer when we were in the island; but, in addition to all this, it is most remarkable that Mr. D'Emmerez, who was appointed in charge of the antimalaria measures after we left, had not detected this mosquito during all these years. The most likely inference appears to me to be that *A. funestus* has been imported quite recently. I wonder whether it has also appeared in Réunion.

In my report I discussed the question whether malaria had been introduced into Mauritius and Réunion in 1866–7 (as was the case) by the introduction of large numbers of coolies from India, or by the introduction of *A. costalis*, and I preferred the latter theory. Against the coolie theory there was the fact that Indians had been pouring into both islands long before those years. I thought it more likely that *A. costalis* had been brought in some time previous to 1866, possibly by some ship. If therefore *A. funestus* has been a new introduction, this hypothesis of mine will be further supported. The entire absence of both species from Rodrigues is another confirmation. The most likely picture appears to me to be that all three islands were Anopheles-free up to 1865 or so, but that two of the islands have become infected since by shipping from Madagascar. I understand that both species are absent from India, but have not been following the recent literature.

It is very disappointing that all the antimalaria measures advised by me have been allowed to fall into abeyance in Mauritius, and I have long been convinced that anti-mosquito work will not be properly carried out in British dominions until stronger discipline is enforced.

RONALD ROSS.

Methods of Chemical Reactions.

THE general scheme of a chemical transformation can be reproduced by the equation:

$$\left.\begin{array}{l} x_1A_aB_bC_c\ldots+x_2A_dB_eC_f\ldots+x_3A_gB_hC_l\ldots+\\ =y_1A_mB_nC_p\ldots+y_2A_qB_rC_s\ldots+y_3A_zB_uC_w\ldots+ \end{array}\right\}\text{I.}$$

A, B, C represent chemical elements or groups of elements, which are transferred as whole complexes from one side to the other of the chemical equation (*i.e.* NH_4, SO_4, NO_2, etc.). We shall call these groups of elements for short the *elementids* of a chemical equation; the chemical elements are thus the simplest elementids. It is evident that in determining the number of elementids of a chemical equation the minimum rule must be observed—that is, the elements must be brought together into groups, so that the number of these groups (elementids) shall be the smallest possible. The composition of these groups must fulfil one condition: that their number taken as a whole and for each formula individually should be the same on the right and on the left side of the chemical equation. In most cases the problem of determining the elementids is simplified by the fact that the number of elementids is the same as the number of elements.

a, *b*, *c*, *d*, etc., as usual in chemical equations, are numbers showing how many times a given element (or elementid) occurs in the composition of a chemical compound. Equation (1) contains molecules composed of all elements of a given chemical transformation; of course, the absence of some elements in the composition of a particular chemical molecule is expressed by making the corresponding multiplier (*i.e.* *a* or *b* or *c*, etc.) equal to zero.

x_1, x_2, x_3, also y_1, y_2, y_3, etc., are the numerical coefficients to be determined by chemists using chemical equations.

To determine these coefficients algebraically, according to the rule requiring an equal number of elements on both sides of a chemical equation, we can write:

$$\begin{array}{l} x_1a+x_2d+x_3g+\ldots=y_1m+y_2q+y_3z+\ldots\\ x_1b+x_2e+x_3h+\ldots=y_1n+y_2r+y_3u+\ldots\\ x_1c+x_2f+x_3l+\ldots=y_1p+y_2s+y_3w+\ldots \end{array}$$

In calculating the numerical values of the coefficients x_1, y_1, x_2, y_2, etc., as required by stoichiometry, the following rules must be observed: first, all the coefficients must be whole and positive numbers; the coefficients must not have a common divisor. This last condition is satisfied by giving the smallest possible whole number to the coefficient of the molecule occurring the least number of times in a chemical reaction.

It follows from the series of equations that the number of elementids of a chemical equation corresponds to the number of separate equations serving to determine the necessary coefficients; and the number of heterogeneous molecules (separate substances) taking part in a chemical reaction corresponds to the number of unknown quantities. Hence:

In the simplest case the number of separate substances taking part in a chemical reaction will be greater by one unit than the number of elementids.

To illustrate this we shall give several chemical equations:

(*a*) *Two elements and three substances:* An example of the simplest reaction is the formation of water (two elements, H and O, and three substances, H_2, O_2, and H_2O).

(*b*) *Three elements or elementids and four substances:*

(1) $2C_2H_4O_2+Zn=Zn(C_2H_3O_2)_2+H_2$; the three elementids are Zn, H, and $C_2H_3O_2$.

(*c*) *Four elements and five substances:*

$$4S+6NaOH=2Na_2S+Na_2S_2O_3+3H_2O.$$

(*d*) *Five elements and six substances:*

$$2Sr(NO_3)_2+6NH_4Cl=2SrCl_2+5N_2+Cl_2+12H_2O.$$

(*e*) *Six elements and seven substances:*

$$K_2Cr_2O_7+6HI+4H_2SO_4=K_2SO_4+Cr_2(SO_4)_3+7H_2O+3I_2.$$

More complex chemical equations containing more than six elementids are comparatively rarely met with in chemistry.

We shall now investigate an example in which seven elements and eight substances take part in a reaction:

$$x_1K_3Co(CN)_6+x_2H_2SO_4=y_1CoSO_4+y_2K_2SO_4+y_3(NH_4)_2SO_4+y_4CO+y_5CO_2+y_6SO_3.$$

By solving the algebraical equations corresponding to this chemical reaction we get the following:

$$2K_3Co(CN)_6+24H_2SO_4=2CoSO_4+3K_2SO_4+6(NH_4)_2SO_4+11CO+CO_2+13SO_3.$$

This reaction is so complex, that even Prof. Treadwell, who did not know of the algebraical method of finding the coefficients, wrote the equation wrongly from the strictly stoichiometrical point of view. His rendering of it was as follows: [1]

$$2K_3Co(CN)_6+12H_2SO_4+12H_2O=2CoSO_4+3K_2SO_4+11CO+CO_2+6(NH_4)_2SO_4+SO_3.$$

[1] Treadwell, "Analytical Chemistry," vol. ii.

Here there are seven elements, but nine substances. One need not be a profound mathematician in order to understand that according to the scheme of a chemical reaction evolved by us, Treadwell's example just given contains, in the equation of reaction, substances the coefficients of which in certain limits can be arbitrarily changed. Such substances are: on one hand, H_2SO_4 and H_2O, on the other SO_3.

Thus, if we express the number of elementids by the letter L, the number of chemical substances taking part in the reaction by the letter M, we shall get for the simplest case of a chemical equation the expression:

$$M = L + 1.$$

We have looked through a number of chemical works and have found no exceptions to this rule. The seeming exceptions, carefully analysed, were found to be only complications, substantiating the rule announced. In the well-known "Analytical Chemistry" of Prof. Treadwell (vol. i.) out of 1240 reactions, 688 follow directly the rule announced. We shall show below that the seeming exceptions are only more complex cases.

Let us consider a first possible complication: it is evident that by addition of two or several chemical equations, we obtain a new chemical equation, but a more complex one; to find in this case the applicability of the simplest rule governing a simple chemical reaction, a special analysis is required.

Let us consider the case of double decomposition, which from a chemical point of view consists of two reactions: a reaction of combination and a reaction of decomposition. This complication affects adversely the immediate applicability of the rule announced. In this case the number of elementids increases, but the new elementids give algebraical equations resulting in the same solutions as those given by the number of equations demanded by the rule $L = M - 1$, so that to find the necessary coefficients it is sufficient to take only the algebraical equations according to our rule. To demonstrate this we will take an example:

$$x_1AgNO_3 + x_2H_2S = y_1HNO_3 + y_2Ag_2S.$$

Here there are the following equations: for Ag, $x_1 = 2y_2$, for NO_3 (elementid), $x_1 = y_1$, for H, $2x_2 = y_1$. These suffice already, for by taking $y_2 = 1$, we obtain $x_1 = 2$, $x_2 = 1$ and $y_1 = 2$. It is possible to make an equation for sulphur, $x_2 = y_2$, but this equation gives no new data and can only serve to control the preceding equations.

Here is another example [2] of a complex reaction:

$$8KClO_3 + 24HCl = 8KCl + 12H_2O + 9Cl_2 + 6ClO_2.$$

The corresponding simple reactions are:

$$KClO_3 + 6HCl = KCl + 3H_2O + 3Cl_2$$
$$5KClO_3 + 6HCl = 5KCl + 3H_2O + 6ClO_2.$$

Adding together the last two equations and dividing throughout by the factor 3 common to all the coefficients, we obtain a more simple expression than that given above, for we get:

$$2KClO_3 + 4HCl = 2KCl + 2H_2O + Cl_2 + 2ClO_2.$$

Here again the "new condition," regulating the decomposition of chlorate of potassium, will be expressed by the quantitative analytical data of the percentages in the reaction products of chlorine and chlorine dioxide. These last examples show already that, as in the application of the familiar phase rule, the appearance of each "new condition" increases by one the number of substances. Designating the number of new conditions by n as in the phase rule, we get for this case the expression:

$$M_n = L + 1 + n.$$

As in the familiar case in the application of the phase rule, we can designate as *non-variant* chemical reactions those following the simple rule $M = L + 1$, as, of course, the formulæ for these reactions do not admit of a variation of coefficients. A chemical reaction obeying the rule $M_n = L + 1 + n$ has n degrees of freedom. Thus the reaction above investigated of the action of sulphuric acid on $K_3Co(CN)_6$, if written according to Treadwell, will have one degree of freedom (inter-relation of the number of molecules H_2O and SO_3), *i.e.* for this case $n = 1$ and thus $M_1 = L + 2$. Accordingly in Treadwell's equation, we have $M_1 = 9$ and $L = 7$.

The reactions of hydrogen peroxide when hydrogen peroxide acts as a reducing agent show this:

$$x_1Ag_2O + x_2H_2O_2 = y_1H_2O + y_2O_2 + y_3Ag.$$

In this case $L = 3$ (*i.e.* Ag, H, and O), $M = 5$, *i.e.* Ag_2O, H_2O_2, H_2O, O_2, and Ag. It would seem that this is an exception to the rule; but actually there is no exception, as the last equation is subject to a new condition: the quantity of hydrogen peroxide and the quantity of silver oxide are determined by the fact that the molecule of oxygen is formed by one atom of oxygen taken from the hydrogen peroxide and one atom of the silver oxide. Algebraically this condition can be expressed by putting $x_1 = x_2$. The solution is then quite definite.

Lastly, let us investigate the case of reactions often met with in organic chemistry, where a small number of elements forms a great many substances. We will take the decomposition by water of the alloy of iron and carbon at high temperature and pressure:

$$3Fe_pC_q + 4_pH_2O = pFe_3O_4 + y_2C_nH_{2n+2} + y_3C_nH_{2n} + y_4C_nH_{2n2} + \ldots$$

An immediate application of the rule $M = L + 1$ can be made only in the case of the formation of one hydrocarbon (case of double decomposition), as in the decomposition of the carbide of aluminium. To the other case the rule $M_n = L + 1 + n$ must be applied, as each new hydrocarbon must be characterised by quantitative analytical data showing its percentage in the reaction products in order to be able to write a stoichiometrically correct chemical equation.

The expression $M_n = L + 1 + n$ and the simpler one $M = L + 1$ form the basis for deducing the algebraical equations necessary for the determination of the equation coefficients of a given chemical reaction. The general number of algebraical equations will be equal to $n + L$, where L is the number of equations corresponding to the number of elementids, and n is the number of equations which must be deduced to meet n special conditions.

All the rules given in this paper can be formulated also by a single expression:

$$M_n \leqq A + 1 + n,$$

where A is simply the number of elements taking part in a given chemical reaction.

WL. KISTIAKOWSKY.

Petrograd, June 1923.

[2] Treadwell, "Analytical Chemistry," vol. i.

Mechanism of the Hydrogen Chlorine Combination.

THE object of the present note is to describe some work in progress here on an attempt to test directly the Nernst theory (*Zeit. Electrochem.*, 24, 335, 1918)

for the very wide deviation of the hydrogen chlorine combination from the Einstein photochemical equivalence law. Nernst postulated that the primary action of the light was to split up the chlorine into atoms, and that these were able to react with hydrogen molecules according to the equation

$$Cl + H_2 = HCl + H,$$

and that the atomic hydrogen formed again reacted with chlorine

$$H + Cl_2 = HCl + Cl,$$

and that this cycle was repeated over and over. Hence 1 quantum of light energy was able to cause a very great amount of combination. He showed that all these reactions proceeded with a free energy decrease and hence were possible reactions.

We are attempting to put this theory to a direct test. In our experiments atomic hydrogen, generated by Wood's method (Trans. Roy. Soc., 102-A, 1, 1922), is led into a mixture of hydrogen and chlorine, and if the theory is correct an excessively large amount of hydrogen chloride should be formed. To determine the amount of atomic hydrogen at the moment of reaction the same procedure is used substituting bromine for chlorine. It is known that the hydrogen bromine reaction does not give excessive yields of hydrogen bromide and Nernst has shown that the reaction

$$Br + H_2 = HBr + H$$

will not take place spontaneously. The hydrogen and chlorine are at a partial pressure of about 1 mm. each, and care is taken to prevent illumination of the gas mixture from the discharge tube. It has been shown so far that atomic hydrogen will travel a distance of 15 cm. from the discharge tube when the pressure is 1 mm. If chlorine be permitted to meet the hydrogen stream at this point direct combination takes place at room temperature; in one experiment the yield of hydrogen chloride was 10 per cent. of the hydrogen used. This amount would seem to exceed greatly that due to the atomic hydrogen present, although so far no direct determination has been made of this quantity.

A. L. MARSHALL.
H. S. TAYLOR.
Princeton University, Princeton, New Jersey,
November 7.

Remarkable Ascending Currents at Melbourne.

REMARKABLE ascending currents were observed during a pilot balloon ascent at Melbourne at 11.00 hours on Friday, October 26, 1923. Heights were determined by means of range-finder readings, and should have no error of consequence. The following table gives the results of the ascent:

Time.		Normal Height.	Observed Height.	Wind.	
				Direction.	Velocity.
min.	sec.	m.	m.	°	m./sec.
	45	90		335	6·8
1	30	180	176	332	10·6
2	15	270	351	325	11·3
3	00	360	801	323	10·9
3	45	450	1202	282	8·3
5	15	630	1580	272	8·8

At the first reading the balloon was too near to be observed with the range-finder. The rate of ascent should have been 100 metres in 45 seconds according to J. S. Dines's formula, but for the particular type of balloon used, range-finder observations indicate that the actual rate is about 90 metres. Shortly after the fifth observation the balloon entered thin cloud, but could be seen for some time longer.

Between the second and last reading the air in which the balloon was travelling ascended at the rate of 4 metres per second, while between the third and fourth the ascending velocity was 8 metres per second. On a number of occasions when cumulus cloud was forming, ascending rates of 2 metres per second over considerable ranges have been observed at Melbourne, but nothing approaching the velocities shown above had been encountered previously. It will be noted that the upward current was at times such that no raindrop could descend through it. A remarkable feature was that the cumulus cloud which was forming rapidly at the time was doing so, not in isolated masses, but in an almost continuous sheet. No cumulo-nimbus was present. Above the cumulus layer alto-cumulus was moving from 252°.

As regards the general situation, an anticyclone was passing to the northwards, moving rapidly. During its passage across the continent the anti-cyclone had decreased in intensity. Melbourne was coming under the influence of the succeeding low-pressure trough. The recent weather had been characterised by these fast-moving anticyclones, the intervening depressions being very poorly developed. This weather is one of the pronounced drought types.

EDWARD KIDSON.
Meteorological Bureau,
Melbourne,
October 29.

Long Range α-Particles.

IN a letter to NATURE of September 22, p. 435, we stated that, in addition to the α-rays of range 6·97 cm., radium active deposit emits particles of ranges 9·3, 11·2, and 13·3 cm. respectively. It has since been found that, in addition to the α-rays of ranges 4·8 and 8·6 cm., thorium active deposit emits particles of ranges 11·5 (previously recorded by Rutherford), 15·0 and 18·4 cm. respectively, and that the emission of every 10^6 α-rays of range 8·6 cm. is accompanied by the emission of 220, 47, and 55 particles of the above ranges. In the case of actinium active deposit evidence of particles of range greater than 6·5 cm. was found, but the sources available were not sufficiently intense to allow their range to be determined with accuracy.

By a method devised by Sir Ernest Rutherford we have satisfied ourselves that the long range particles from radium active deposit are α-rays.

Polonium has also been examined and found to emit small numbers of particles of ranges 6·1±0·1, 10·0±0·1 and 13·1±0·2 cm. respectively, in addition to the main group of α-rays of range 3·93 cm. The relative numbers in these new groups are at present being determined; from the brightness of the scintillations it is considered that they are α-rays.

L. F. BATES.
J. STANLEY ROGERS.
Cavendish Laboratory, Cambridge,
December 15.

Continental Drift and the Stressing of Africa.

IN reply to Dr. Evans's letter under the above title in NATURE of September 22, p. 438, may I say that I too shall be surprised, indeed extremely surprised, if further work in Uganda does not "disclose the existence of at least some normal faulting with a north and south strike, showing the former existence of east and west tension." Compression in one area seems to imply tension in another; and it is not very

probable that Africa has always been on one side of the equation. But one would expect that, had the continent been "predominantly in a state of tension," evidence of the fact would not be difficult to find in Uganda.

True, there is no reason why "a change of conditions may not convert a true rift valley formed in a period of tension into one bounded by reversed faults." But it may also be observed that it is certain that tension operating on a rift formed by a thrust action would accentuate the features, provided that the bottom of the valley was not prevented by subterranean support from sinking. Compression would do the same without the last proviso; while some such factor as cooling at depth would achieve a similar result without the assistance of either tension or compression if the faults were reversed.

There can be no shadow of a doubt that the bottoms of the Uganda rift valleys have sunk, and that, too, very considerably. What has happened beyond this it is impossible for any living soul to say with absolute certainty at present; but no theory of the rift will pass muster if it leaves Ruwenzori hanging in the air, and if it fails to explain why planes of weakness to tension have not been utilised.

Assuming a rift-block (by which I mean the mass between the rift features) bounded by reversed faults to sink, something must happen to the valley sides; either one or both will subside as a whole, or great lines of normal faulting will appear in the country on one or both sides; or these two things may happen in combination. The first of these alternatives appears, almost to the entire exclusion of the second, by Lake Albert, in Bunyoro; the second, largely to the exclusion of the first, is seen along the eastern side of Lake George. Moreover, normal faulting may appear in the rift-block itself. But all these things may equally be consequent upon settlement of a rift-block bounded by normal faults. Thus it is easily seen that step faulting is not admissible as evidence as to the nature of the fractures that initiated the rift. The solution of the Great Rift Valley problem must be sought, in fact, in places like Bunyoro, where step faulting is almost completely absent.

Dr. Evans, who combines Wegener's general proposition with a tentative theory of the moon's birth, would expect (subject to the truth of the latter) "The chief period of tension in Africa and its surroundings to have existed in Mesozoic and early Kainozoic times"; but this is precisely when, so Prof. J. W. Gregory argues (and I agree with him), Africa was being hunched up by compression.

As to the date of the moon's birth, or the manner of it, I am not qualified to speak with any authority; but I should have thought that had it taken place as late as the Carboniferous period, the parting at least would have been catastrophic. Also I am tempted to ask (not controversially, but as one seeking information) why if "the bulk of the atmosphere" was "attracted towards the protruding mass of the moon," our satellite has now no atmosphere worth mentioning. Did the moon escape without air or water; or may it not be that it once possessed both, self-elaborated very long ago, as those of the earth, in an early stage of its individual career? May not the absence of atmosphere be indicative of completion in the life of a celestial body of a stage the span of which is a function of the sphere's mass?

I fear that I have somehow created the impression that all the major faulting in this part of the world is more or less north and south. This is not so. In Bunyoro certainly, and one has reason to believe elsewhere, a series of very large east to west faults is traceable. This is clearly brought out in a structure map of part of Bunyoro prepared by Mr. W. C. Simmons a few years ago. Judging by the manner in which they cut off the north to south fractures, the east to west faults are the younger; though both are very ancient.

I believe that the word "rift" was originally applied to the Great East African fracture trough, which is quite a different thing from an ocean-covered area produced by the drifting of continents. Rift valley faults will still remain rift valley faults, whether they turn out to be normal or reversed; otherwise "rift valley" must disappear from our nomenclature should my hypothesis prove true.

I thoroughly agree with Dr. Evans's remarks with regard to the value of speculative hypothesis; and, as he reminds us, "It will only be when we have all the facts before us, that we shall be able to solve with any assurance the problems presented by the present configuration of the surface of the globe."

E. J. WAYLAND.

Mahyuro, Lake George, Uganda,
November 3.

Mrs. Hertha Ayrton.

IN NATURE of December 1 there appears under the above heading an obituary notice of the late Mrs. Ayrton which, I regret to say, is in some matters incorrect and misleading. The article is an unusual one, for in it the writer ventilates his own grievances against his so-called "masters" (The City and Guilds Institute), and disparages and belittles the work and abilities of his lifelong colleagues. To write in this strain about dead friends is in my opinion reprehensible, and it is to be hoped the example will not be followed.

From reading Prof. Armstrong's article one would gather that Mrs. Ayrton had little originality, and that all the scientific work she did was due to her husband's lead. Neither inference would be true, as is proved by the inventions she made before she met Prof. Ayrton and the original work she carried out after his death. In connexion with the latter, Mrs. Ayrton took out eight patents between 1913 and 1918.

The late Prof. Ayrton told me on several occasions that when Mrs. Ayrton took up the study of the electric arc he left the subject entirely alone so that there should be no excuse for any one giving him the credit for her work, and when lecturing to his students on the arc he made similar statements, as many of his pupils can doubtless confirm; it is indeed very probable that Prof. Armstrong heard analogous remarks from Prof. Ayrton's own lips. T. MATHER.

37 Wyatt Park Rd.,
Streatham Hill, S.W.2,
December 10.

A Waltzing Mouse.

IT may perhaps be of interest to record that, in some recent experiments in crossing mice, there appeared in a litter of seven (self-coloured champagne) a female which exhibited all the symptoms associated with the Japanese waltzing mouse of which Yerkes made a fairly exhaustive study. It is dextro-rotatory, if the term be permitted. It is not yet old enough for reproduction. Both parents have, however, since produced litters, the female to a Dutch-marked male, the male on a Dutch-marked female, five and four respectively, but all are normal, nor out of eighty mice recently born to other couples have I had any other that waltzes.

G. W. HARRIS.

The Royal Automobile Club, London, S.W.1,
November 25.

Egypt as a Field for Anthropological Research.[1]

By Prof. P. E. NEWBERRY, M.A., O.B.E.

IT has often been stated that civilisation in Egypt spread from the south, and considerable stress has been laid upon the fact that many pre-dynastic and early dynastic remains have been found in Upper Egypt in the region between Edfu and Thinis, especially at Hierakonpolis and Naqada, and north of Naqada, in the neighbourhood of Abydos. Opposite Edfu is a desert route leading to the Red Sea; at Kûft, opposite Naqada, is the beginning of the road leading to Kosêr, the port on the Red Sea. It has been thought that the people who brought culture to Egypt reached the Nile Valley by one or by both these routes from a "God's Land" situated somewhere down the Red Sea coast. But throughout the whole history of Egypt, culture has always come from the north, and spread southwards.

From a study of the monuments of the First Dynasty that had been found at Abydos and elsewhere in Upper Egypt I ventured, nearly twenty years ago, to suggest the existence in pre-dynastic times of a Delta civilisation which, in culture, was far advanced beyond that of Upper Egypt, and I pointed out that it was probably to a Delta civilisation that the Dynastic Egyptians owed their system of writing. I was led to this conclusion by the following facts. Although many pre-dynastic cemeteries had been thoroughly explored in Upper Egypt, no grave had yielded a single fragment of hieroglyphic writing. The only inference that can be drawn from this is that hieroglyphic writing was unknown, or at all events unpractised, by the inhabitants of Upper Egypt before Dynastic times. On the other hand, the discoveries at Naqada, Hierakonpolis, and Abydos had shown us that all the essential features of the Egyptian system of writing were fully developed at the beginning of the First Dynasty. Hieroglyphic signs were already in full use as simple phonograms, and their employment as phonetic complements was well established. Determinative signs are found beginning to appear in these early writings, but, as Erman and Griffith have noticed, even as late as the Fifth Dynasty their use was very restricted in the monumental inscriptions, although they were common in the cursive and freely written texts of the pyramids. At the very beginning of the First Dynasty the numerical system was complete up to millions, and the Egyptians had already worked out a solar year of 365 days. This was indeed a remarkable achievement.

These facts are of great significance, for it is clear that the hieroglyphic system of writing, as we find it at the beginning of the First Dynasty, must have been the growth of many antecedent ages, and yet no trace of the early stages of its evolution have been found on Upper Egyptian soil. There is no clear evidence, however, that the system was borrowed from any country outside Egypt; the fauna and flora of its characters give it every appearance of being indigenous. It is apparent, therefore, that we must seek the cradle of the Egyptian system of hieroglyphic writing elsewhere than in Upper Egypt, and as the fauna and flora of its characters are distinctly Egyptian, the presumption is that it must be located in the Delta. An important indication as to the original home of Egyptian writing is given by the signs which, in historic times, were used to designate the points of the compass. The sign for "east" was a drop-shaped ingot of metal upon a sacred perch, and this was the cult-object of a clan living in pre-dynastic times in the Eastern Delta. The sign for "west" was an ostrich feather placed in a semicircular stand, and this was the cult-object of the people of the Western Delta. The sign for "south" was a scirpus-reed; this was the cult-object of a clan which dwelt on the east bank of the Nile a little above the modern village of Sharona in Middle Egypt. The country south of the apex of the Delta was known as Ta Shema, "Reed Land." It must, therefore, have been at some point north of the apex of the Delta that the scirpus-reed was first used to designate the south. It must also have been somewhere in the Central Delta that the cult-objects of the peoples of the Eastern and Western Delta were first used to designate east and west.

For the Delta being the early home of writing another fact has to be taken into consideration. Thoth, the Ibis-god, was to the Egyptians the god of writing, and it was to him that they attributed its invention. The principal seat of his worship in historic times was Hermopolis, in Middle Egypt. But Thoth's original habitat was situated in the north-east corner of the Delta, where, in pre-dynastic times, had resided an Ibis clan. The tradition that named Thoth as the god and inventor of writing would, therefore, point Delta-wards. This tradition is significant also in another way. Although we cannot doubt that the Egyptian system of writing was evolved in the Delta, the germs of writing may have come into Egypt from Western Asia *via* this north-east corner of the country. In this connexion it may be pointed out that the hieroglyphic signs for "right" and "left" were the same as those for "west" and "east"; the Egyptians who evolved the hieroglyphic system of writing orientated themselves facing south.

It is remarkable that so little is known about the early history of the Delta. Few excavations have been carried out there, and nothing of pre-dynastic, or early dynastic, times has, so far, been brought to light from the country north of Cairo. We do know, however, that before the arrival of the Falcon-kings from Hierakonpolis in the south, Middle and Lower Egypt had been, probably for many centuries, united under one sceptre, and that before these two parts of the country were united there had been a Delta Kingdom which had had its capital at Sais. The names of some of these early kings are preserved on the Palermo fragment of the famous Annals Tablet, and the list there given would alone be enough to prove how ancient the Delta civilisation must have been. There was certainly nothing comparable with it in Upper Egypt in those far-off days.

What were the physical conditions prevailing in the Delta and in the regions to the east and west of it immediately preceding the arrival of Menes in Lower Egypt? For the eastern side the evidence is exceedingly scanty, but there is one fact which is significant.

[1] From the Presidential Address delivered to Section H (Anthropology) of the British Association at Liverpool on September 17.

The chief god of the eastern nomes of the Delta in the Pyramid Age was Anzety, a pastoral deity who was the prototype of Osiris. He is represented as a man holding in one hand the shepherd's crook, and in the other the goatherd's ladanisterion. There can be little doubt, therefore, that in the Eastern Delta there lived a pastoral people who possessed flocks of sheep and goats, and this is evidence of a certain amount of grass-land. In the Central Delta at the same period there lived a series of clans, among which a Bull Clan was predominant. In historic times in Egypt the ox is often figured roaming in papyrus and reed marshes, and it may be that the Central Delta marshes supported herds of domesticated cattle.

Much more is known about the western side of the Delta at the time of Menes. It formed, I believe, part of what was called Tehenu-land; at all events this name was given to the region immediately to the west of the Canopic branch of the Nile. There can be no doubt that this part of the country was a very fertile and prosperous region in the period immediately preceding the First Dynasty. Its name signifies "Olive-land," and we actually see these trees figured, with the name of the country beside them, on a pre-dynastic Slate Palette; on this Palette, above the trees, are shown oxen, asses, and sheep of the type later known as ser-sheep. It was Menes, the Falcon-king of Upper Egypt, who conquered the people of Tehenu-land. This conquest is recorded on a small ivory cylinder that was found at Hierakonpolis. Another record of the southerner's triumph over these people is preserved on his famous Slate Palette; here the Upper Egyptian king is depicted smiting their chieftain, while on the verso of the same Palette is the scene of a festival at the Great Port, which was perhaps situated near the Canopic branch of the Nile. The mace-head of Menes, which is now in the Ashmolean Museum at Oxford, has a scene carved upon it which shows the king assuming the Red Crown of Sais, and the inscription accompanying it records that he had captured 120,000 prisoners, 400,000 oxen, and 1,422,000 goats. This immense number of oxen and goats is clear evidence that the north-western Delta and the region to the west of it (Tehenu-land) must have included within its boundaries very extensive grass-lands.

The history of this part of the Delta is most obscure. During the period that elapsed from the end of the Third Dynasty to the beginning of the Twenty-third, when Tefnakht appears upon the scene, we have scarcely any information about it. What was happening at Sais and other great cities in the north-west of Egypt during the period from 2900 to 720 B.C.? There is an extraordinary lacuna in our knowledge of this part of the country. The people living there were certainly of Libyan descent, for even so late as the time of Herodotus the inhabitants deemed themselves Libyans, not Egyptians; and the Greek historian says that they did not even speak the Egyptian language. The pre-dynastic people who inhabited the greater part of the Lower Nile Valley were apparently of the same stock as these Libyans. There is a certain class of decorated pottery which has been found in pre-dynastic graves from Gizeh in the north to Kostamneh in the south. On this decorated pottery are figured boats with cult-objects raised on poles. Altogether some 170 vases of this type are known, and on them are 300 figures of boats with cult-signs. Of these, 124 give the "Harpoon" ensign; 78 the "Mountain" ensign; and 20 the "Crossed Arrows" ensign. These cult-objects all survived into historic times; the "Harpoon" was the cult-object of the people of the Mareotis Lake region; the "Mountain" and "Crossed Arrows" were the cult-objects of the people dwelling on the right bank of the Canopic branch of the Nile. Thus it will be seen that out of 300 boats figured on vases found in graves in the Lower Nile Valley south of Cairo, 222 belong to cults which can be located in the north-western corner of the Delta. At the beginning of the historic period the cult-objects of the people of the north-western Delta included (1) the "Harpoon," (2) the figure-of-eight "Shield with Crossed Arrows," (3) the "Mountain," and probably (4) the "Double Axe," and (5) a "Dove" or "Swallow." With the exception of the "Harpoon" all these cult-objects are also found in Crete, a fact which is significant in view of Sir Arthur Evans's remark to the effect that he considers the possibility of some actual immigration into Crete of the older Egyptian element due to the first Pharaohs. The "Harpoon," it should be noted, is the prototype of the bident, and later, of the trident of the Libyan god Poseidon. Here in this western side of Lower Egypt is an almost wholly unexplored field for the anthropologist.

I have already referred to the pastoral deity Anzety, who, in the Pyramid Age, was chief of the nomes of the Eastern Delta. Among all the nome-gods he is the only one that is figured in human form; he stands erect holding in his right hand the shepherd's crook, and in his left the goatherd's ladanisterion. On his head is a bi-cornate object that is connected with goats. In the Pyramid Texts, Anzety is entitled "Head of the Eastern nomes," and these included the ancient one of the Oxyrrhynchus-fish, where, later, the ram or goat was the chief cult-animal. Neither the domesticated sheep nor the goat can be reckoned as Egyptian in origin; they both came into Egypt from Western Asia. We have, therefore, in this pastoral deity Anzety evidence of immigration from the west.

Among the cult-objects of the cities over which the god Anzety presided were two which, I believe, can definitely be referred to trees that were not indigenous to the soil of Egypt but to Syria. One of these cult-objects is the so-called Ded-column. This was one of the holiest symbols of the Egyptian religion. It has four cross-bars at the top like superposed capitals. Sometimes a pair of human eyes are shown upon it, and the pillar is draped: sometimes a human form is given to it by carving a grotesque face on it, robing the lower part, crowning the top with ram's horns, and adding two arms, the hands holding the crook and ladanisterion. Frazer has suggested that this object might very well be a conventional representation of a tree stripped of its leaves. That it was, in fact, a lopped tree is, I believe, certain. In the Pyramid Texts it is said of Osiris, "Thou receivest thy two oars, the one of juniper (*uan*), the other of *sd*-wood, and thou ferriest over the Great Green Sea." The determinative sign of the word *sd* is a tree of precisely the same form as the Ded-column that is figured on early Egyptian monuments, *i.e.* it has a long, thin stem.

This tree-name only occurs in inscriptions of the Pyramid Age, and it is mentioned as a wood that was used for making chairs and various other articles of furniture. In the passage quoted from the Pyramid Texts it is mentioned together with juniper, and the latter was employed in cabinet-making, etc., at all periods of Egyptian history. There is no evidence that juniper ever grew in Egypt, but we have numerous records of the wood being imported from the Lebanon region. The *sd*-tree, as we see from the determinative-sign of the name, had horizontally spreading branches, and was evidently some species of conifer. No conifers, however, are known from Egypt; the *sd*-wood must, therefore, have been of foreign importation. As it is mentioned with juniper, which we know came to Egypt from Syria, it is possible that it came from the same region. Among the trees of the Lebanon there are four that have horizontally spreading branches. These are the cedar (*Cedrus libani*), the Cilician fir, *Pinus laricio*, and the horizontal-branched cypress (*Cupressus sempervirens* var. *horizontales*).

Much misconception at present exists with regard to the Lebanon Cedar, because the name "cedar" is applied to a large number of woods which are quite distinct from it, and the wood which we generally call cedar (*e.g.* the cedar of our "cedar" pencils) is not true cedar at all, but Virginian juniper. The wood of *Cedrus libani* is light and spongy, of a reddish-white colour, very apt to shrink and warp badly, by no means durable, and in no sense is it valuable. Sir Joseph Hooker, who visited the Lebanon in 1860, notes that the lower slopes of that mountain region bordering the sea were covered with magnificent forests of pine, juniper, and cypress, "so that there was little inducement for the timber hewers of ancient times to ascend 6000 feet through twenty miles of a rocky mountain valley to obtain cedar wood which had no particular quality to recommend it. The cypress, pine, and tall, fragrant juniper of the Lebanon, with its fine red heart-wood, would have been far more prized on every account than the cedar." The *sd*-tree was, I believe, the horizontal-branched cypress, which is common in the wild state. In the Middle Ages this tree was believed to be the male tree, while the tapering conical-shaped cypress was considered to be the female. This is an interesting fact, because there is some evidence to show that the tapering variety was the symbol of Hathor-Isis, while the horizontal-branched one was the symbol of Osiris.

Not far from the city of Osiris in the Delta was Hebyt, the modern Behbeyt el Hagar. Its sacred name was Neter. The Romans called it Iseum. It was the ancient seat of Isis-worship in Egypt, and the ruins of its temple to that goddess still cover several acres of ground in the neighbourhood. On the analogy of other sacred names of cities the primitive cult-object here was the *ntr*-pole. This was not an axe, as has so often been supposed, but a pole that was wrapped around with a band of coloured cloth, tied with cord half-way up the stem, with the upper part of the band projecting as a flap at top. Dr. Griffith conjectured that it was a fetish, *e.g.* a bone carefully wound round with cloth, but he noted that "this idea is not as yet supported by any ascertained facts." As a hieroglyph this wrapped-up pole expresses *ntr*, "god," "divine," in which sense it is very common from the earliest times; gradually it became determinative of divinity and of the divine names and ideographic of divinity. Another common ideograph of "god" in the Old Kingdom was the Falcon (Horus) upon a perch, and this sign was also employed as a determinative of divinity and of the names of individual gods; it even sometimes occurs as a determinative sign of the *ntr*-pole, *e.g.* Pyr. Texts, 482. This use of the Falcon indicates that in the early dynasties the influence of the Upper Egyptian Falcon-god (Horus) was paramount.

There is reason, however, for believing that the *ntr*-pole cult had at an earlier period been the predominant one among the writing people of the Delta; this, I think, is shown by the invariable use of the *ntr*-pole sign in the words for priest (*hm-ntr*, god's servant) and temple (*ht-ntr*, god's house). Now, on a label of King Aha of the First Dynasty there is a representation of the temple of Neith of Sais. Here two poles with triangular flags at top are shown on either side of the entrance. Later figures of the same temple show these poles with the rectangular flags precisely as we find in the *ntr*-sign. A figure of the temple of Hershef on the Palermo Stone shows two poles with triangular flags, while a Fourth Dynasty drawing of the same temple shows the same poles with rectangular flags. We see, therefore, that the triangular-flagged pole equals the rectangular-flagged one, and that the *ntr* is really a pole or mast with flag.

Poles of this kind were probably planted before the entrances to most early Egyptian temples, and the great flag-masts set up before the pylons of the great temples of the Eighteenth and later dynasties are obviously survivals of the earlier poles. The height and straightness of these poles prove that they cannot have been produced from any native Egyptian tree; in the Empire, flag-staves were regularly imported from Syria; it is probable, therefore, that in the earlier times they were introduced from the same source. A well-known name for Syria and the east coast of the Red Sea, as well as of Punt, was Ta-ntr, "the land of the *ntr*-pole." This was the region in which the primitive Semitic goddess Astarte was worshipped. In Canaan there was a goddess Ashera whose idol or symbol was the ashera pole. The names of Baal and Ashera are sometimes coupled precisely as those of Baal and Astarte, and many scholars have inferred that Ashera was only another name of the great Semitic goddess Astarte. The ashera-pole was an object of worship, for the prophets put it on the same line with the sacred symbols, such as Baal pillars; the ashera was, therefore, a sacred symbol, the seat of a deity, the mark of a divine presence. In late times these asherîm did not exclusively belong to any one deity; they were erected to Baal as well as to Yahw. They were sign-posts set up to mark sacred places, and they were, moreover, draped. They correspond exactly to the *ntr*-poles of Egyptian historic times.

I have noted that these *ntr*-poles were tall and straight. What tree produced them? In Egyptian inscriptions there is often mentioned a tree named *tr.t.* It was occasionally planted in ancient Egyptian gardens, and specimens of it were to be seen in the Temple garden at Heliopolis. The seeds and sawdust were employed in medicine, and its resin was one of

the ingredients of the Kyphi-incense. Chaplets were made of its twigs and leaves. The tree was sacred to Hathor; branches of it were offered by the Egyptian kings to that goddess. In a Saite text it is mentioned with three other trees, pine, yew, and juniper; these are all found in Northern Syria, where they grow together with the cypress; the *tr.t* tree may therefore be the cypress. Evidence has been brought forward to show that the *sd*-tree is the horizontal-branched cypress, which was believed to be a male tree, while the tapering, flame-shaped cypress was believed to be the female tree. The Ded-column was the symbol of Osiris, and at Busiris a festival of raising this column was celebrated. The *tr.t* tree was sacred to Hathor, who is often identified with Isis, and there was a festival of raising the *tr.t* tree that was celebrated on the nineteenth day of the first month of the winter season. It is not known where this festival was celebrated, but it may well have been at Neter, the seat of the Isis cult near Dedu-Busiris. The two tree-cults point to Northern Syria as the country of their origin.

In the architecture of ancient Egypt two distinct styles can be recognised. One is founded on wattle-and-daub, the other on wood construction. Wattle-and-daub is the natural building material of the Nile Valley and Delta, and the architectural forms derived from it are certainly indigenous. Those styles derived from wood construction, on the other hand, could not have originated in Egypt; they must have arisen in a country where the necessary timber was ready at hand. Egypt produces no coniferous trees and no timber that is at all suitable for building purposes, or indeed for carpenter's work of any description. The wood of the sycomore-fig is very coarse-grained, and no straight planks can be cut from it. The sûnt-acacia is so hard that it requires to be sawn while it is green; it is very irregular in texture, and on account of the numerous branches of the trunk it is impossible to cut it into boards more than a couple of feet in length. The palaces of the early kings of the Delta were built of coniferous wood hung with tapestry-woven mats. The tomb of Menes' queen, Neith-hotep, at Naqada, was built of brick in imitation of one of these timber-constructed palaces, and smaller tombs of the same kind are known from the Second and Third Dynasties, but not later. As early as the reign of King Den (First Dynasty) the palaces of this type were beginning to be built of the native wattle-and-daub in combination with wood, and by the end of the Pyramid Age the style disappears entirely, though the memory of it was preserved in the false-doors of the tombs and stelæ. Brick buildings similar to those of the "palace" style of Egypt are also known from early Babylonia, and they were at one time regarded as peculiarly characteristic of Sumerian architecture. These, obviously, must have been copied, like the Egyptian, from earlier timber forms. In Babylonia, as in Egypt, timber was scarce, and there are records that it was sometimes obtained from the coast of Syria. This was the region from which the Egyptians throughout historic times obtained their main supplies of wood, so it is not improbable that they, as well as the Sumerians, derived this particular style of architecture from Northern Syria. I may observe in passing that in this "palace" style we have the transition form between the nomad's tent and the permanent building of a settled people.

The lack of native timber in Egypt is significant in another direction. Boats of considerable size are figured on many pre-dynastic monuments. They are long and narrow, and in the middle there is usually figured a reed or wicker-work cabin. In my view these boats were built, like many of those of later periods in Egypt, of bundles of papyrus reeds bound together with cord; they were, in fact, great canoes, and, of course, were only for river traffic. They were not sailing boats, but were propelled by means of oars. No mast is ever figured with them, but they generally have a short pole amidships which is surmounted by a cult-object. On one pre-dynastic vase there is a figure of a sailing ship, but this is totally different in build from the canoes, and it has a very high bow and stern with its mast set far forward in the hull. Similar vessels are figured on the ivory knife-handle of pre-dynastic date from Gebel el Araq, but these vessels appear to be in port and the sails are evidently lowered.

I have already referred to the Great Port mentioned on the Palette of Menes. A port implies shipping and trade relations with people dwelling along the coast or across the sea. It may be that the people of the north-western Delta built wooden ships, but if they did they must have procured their timber from some foreign source. Coniferous wood was already being imported into the Nile Valley at the beginning of the First Dynasty from the Lebanon region, and it must be remembered that the Egyptian name for a sea-going ship was *kbnyt*, from Keben, "Byblos," the port of the Lebanon, where these ships must have been built and from whence they sailed. The sacred barks of the principal gods of Egypt in historic times were invariably built of coniferous wood from the Lebanon. Transport ships on the Nile were sometimes built of the native sûnt-wood, and Herodotus describes them as made of planks about two cubits long which were put together "brick-fashion." No masts or sail-yards, however, could possibly be cut from any native Egyptian tree. In the Sûdan at the present day masts are sometimes made by splicing together a number of small pieces of sûnt and binding them with ox-hide, but such masts are extremely liable to start in any gale, and they would be useless for sea-going ships. It may be doubted whether the art of building sea-going ships originated in Egypt.

It may be doubted also whether the custom of burying the dead in wooden coffins originated in Egypt. In countries where a tree is a rarity a plank for a coffin is generally unknown. In the Admonitions of an Egyptian Sage written some time before 2000 B.C., at a period when there was internal strife in Egypt, the Sage laments that "Men do not sail northwards to [Byb]-los to-day. What shall we do for coniferous trees for our mummies, with the produce of which priests are buried, and with the oil of which [chiefs] are embalmed as far as Keftiu? They come no more." This ancient Sage raises another anthropological question when he refers to the oil used for embalming. The only oils produced by native trees or shrubs in Egypt were olive oil, ben oil from the moringa, and castor oil from the castor-oil plant. The resins and oils used for embalming were principally

those derived from pines and other coniferous trees. Egypt produced no kinds of incense trees or shrubs. The common incenses were pine resin, ladanum, and myrrh, and all these were imported. It is difficult to believe that the ceremonial use of incense arose in Egypt.

These are a few of the questions raised by a study of the material relating to the origins of the ancient civilisation of Egypt. An immense vista has been opened out before our eyes by the discoveries of the last thirty years, and now, in Egypt better than in any other country in the world, we can see man passing from the primitive hunter to the pastoral nomad, from the pastoral nomad to the agriculturist, and then on to the civilised life which begins with the art of writing. We can see in the Delta and in the Lower Nile Valley tribes becoming permanently settled in fixed abodes around primitive cult-centres, and then uniting with others into one community. We can trace the fusion of several communities into single States, and then, later, the uniting of States under a supreme sovereign. What other country in the world preserves such a record of its early history?

Rare Gas Discharge Lamps.

By J. W. RYDE, Research Laboratories of the General Electric Company, Ltd., Wembley.

A DISCHARGE of electricity through a gas at atmospheric pressure generally takes the form of a luminous spark which will pass only under a potential gradient of several thousand volts per centimetre. If, however, the pressure of the gas is reduced, the appearance of the discharge changes. First it spreads out into wavy streamers; the streamers then broaden until the discharge tube is filled with a diffuse luminous glow extending from the positive electrode to within a short distance of the cathode. This glow is known as the positive column. The cathode is now covered with a layer of bright luminosity called the negative glow, and on close inspection is seen to be not quite in contact with the electrode but separated from it by a thin and sharply defined region, known as the Crookes's dark space. Another less well-defined dark region, the Faraday dark space, is between the negative glow and the positive column. Further reduction of the pressure results in a widening of both dark spaces and the negative glow, the positive column at the same time becoming correspondingly shorter. At still lower pressures the Crookes's dark space increases until finally it fills the whole tube and there is no further luminosity of the gas.

The potential necessary to start the discharge depends on the pressure and nature of the gas, the form and material of which the electrodes are made, and also on the distance between them. In a given gas with given electrodes the starting potential is large at high pressures, but decreases, in an almost linear relation, with decrease of pressure, reaching a minimum at what is called the critical pressure, after which it rises again very rapidly. The pressure at which the minimum occurs depends on the form of the electrodes, their distance apart and the nature of the gas, but the minimum itself depends on the nature of the gas and the material and form of the cathode employed. It is about 200 volts for neon, 280 volts for hydrogen, 340 volts for air, and 420 volts for carbon dioxide. Small traces of impurity affect these values to a great extent; thus, the addition of only 0·5 per cent of pure hydrogen to neon reduces the minimum starting potential by nearly 50 volts, 5·0 per cent reduces it by about 60 volts, but if more than 5·0 per cent is added the hydrogen ceases to act as an impurity and begins to show its own characteristics, so that the starting voltage rises again. On the other hand, small quantities of other gases, such as oxygen, raise the starting potential instead of lowering it. The material of which the cathode is made has also some effect. The figures given above refer to cathodes of ordinary metals such as iron, nickel, or copper, etc., between which there are only small differences, but with magnesium, barium, or the alkali metals the starting voltage is considerably reduced; in fact, with certain alloys of these metals, the glow discharge can be started in neon at a potential so low as 90 volts and may be maintained at 58 volts.

When once the discharge has started, the potential can be lowered somewhat before the discharge stops.

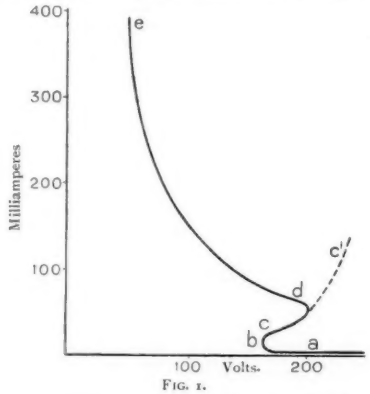


FIG. 1.

The curve connecting this "going out" voltage and the pressure is roughly similar to the starting voltage curve, but is displaced to a position somewhat below it on the voltage ordinate.

If the electrodes are only a short distance apart, so that the positive column is absent, the relation between the current flowing and the potential applied across the electrodes is that shown in Fig. 1. The states represented by the lower and upper parts of the curve are unstable, and can be observed only if there is in series with the discharge an appropriate resistance, by means of which the current may be varied. With this arrangement, when the current is only of the order of a micro-ampere, a faint glow is seen some distance from the cathode. The potential between the electrodes falls rapidly as the current is increased, and at the same time the glow becomes brighter and assumes the form of a sharply defined patch moving nearer and nearer to the cathode as the current rises. The voltage now remains sensibly constant, being that known as the normal cathode fall, which is the lowest potential at which

the unsupported discharge can be maintained. With a further increase of current, the glow spreads laterally over the cathode, its intrinsic brilliancy and the current density remaining practically constant. A value of the current is eventually reached at which the cathode becomes completely covered with a layer of glow separated from it by the Crookes's dark space, which is only a fraction of the width of the layer of glow itself. Any further increase in current brings us to the part *c* of the curve; the voltage now increases with increase of current and the glow becomes brighter and the dark space narrower. The curve eventually becomes very steep, following the path *cc'*, and currents of the order of several amperes per square centimetre of cathode surface can be passed. At some part of the curve *cc'* the cathode begins to heat up considerably, and if composed of a refractory metal such as tungsten, will become white-hot; thermionic emission then takes place and the glow discharge passes over to the arc discharge. As soon as this begins the potential difference between the electrodes begins to decrease as the current rises, and may finally drop to only a few volts.

Gas discharge lamps may be divided into three classes, namely: (1) Lamps in which practically all the light is emitted by the positive column, (2) negative glow lamps in which the positive column is absent, and (3) lamps in which the light is emitted not from the gas but from the cathode itself, which is rendered incandescent by the discharge.

Lamps of the Moore type belong to the first class. They consist of a long glass tube filled with gas to a pressure of a few millimetres and having an electrode at each end. On account of the distance between the electrodes, the operating potential usually amounts to several thousand volts and is inconveniently high. Recently, short tubes of this type containing neon, and having electrodes made of alkali metal alloys, have been developed which will run on 220 volt A.C. supply, but require a special device giving a higher voltage for starting. These lamps are very efficient; with some of the tubes an efficiency of 0·65 watts per candle is obtainable. The colour of the light, however, is a brilliant orange red, which for many purposes is objectionable.

The second class of lamp was developed to run directly on ordinary lighting circuits. The electrodes are placed a few millimetres apart in a small bulb, the distance between them being such that the positive column is absent; this is to enable them to start and run at ordinary supply voltages. The gas used for filling the lamps is neon with about 20 per cent. of helium, which is separated with it during the process of extraction from the air. The advantages of neon are threefold. In the first place, most of the energy radiated from the glowing gas lies in the visible spectrum; secondly, the starting potential is lower than in other gases; and thirdly, the colour of the light emitted, being a yellow orange, is more suitable for illumination purposes than that from any other gas. By using hydrogen to reduce the starting voltage as explained above, and by filling the lamps to about the critical pressure (10 mm.), it is possible to make lamps having iron electrodes in which the discharge will start at about 150 volts.

The whole of the light from these lamps comes from the negative glow, which appears as a layer of bright orange luminosity about two millimetres thick completely covering the cathode, whatever its size or shape. The Crookes's dark space at the pressure used is only a fraction of a millimetre thick and is not easily seen. In consequence, the luminosity takes the form of the cathode, so that if this electrode is formed out of a sheet of metal in the shape of a letter, numeral, or similar sign, it will appear brilliantly illuminated when the discharge is passing. It is in this form that the tube is used for advertising purposes. In cases where the lamp is required for dim illumination, the cathode is made of a spiral of wire in the shape of a beehive, which ensures an approximately even distribution of light in all directions. The other electrode is either an iron wire hidden behind the letter, or a plate inside the spiral. On direct current only one electrode becomes illuminated, but on alternating current the small electrode also glows during the half cycle when it becomes the cathode.

On account of the rigidity of the mechanical construction, the lamps are robust and their life is limited only by their progressive blackening. This blackening is due to particles of the cathode which are shot off during the passage of the discharge and collect in the form of a film on the bulb. The rate at which the blackening takes place depends on the current passing through the lamp, and also varies very greatly with the particular metal used for the electrodes and the nature of the gas. The addition of impurities which lower the starting potential of the gas also considerably reduces the blackening. Thus, with iron electrodes and pure neon, the useful life of the lamp would only be about 80 hours, while with an addition of a small percentage of hydrogen the life becomes of the order of 1000 hours or more. A series resistance placed in the caps of the lamps makes them suitable for various voltages, and at the same time reduces the current to a value leading to a reasonable life.

These lamps, in common with all forms of Geissler discharge tubes, possess many properties which are valuable for purposes other than that of lighting. For example, when running on the part *ab* of the curve of Fig. 1 they can act as a negative resistance and can be used to generate oscillations. They are also sensitive detectors of current; the luminosity produced by a current of one microampere is easily seen if the lamp is shielded from direct daylight. But these other developments cannot be treated here.

In the third class of lamp, the electrodes are usually tungsten spheres about one millimetre in diameter and placed one millimetre apart. The bulb is filled with neon to about 50 mm. pressure. When first switched on, an intense glow discharge takes place which heats the cathode white-hot; a thermionic emission then ensues and the potential across the lamp drops to about 25 volts, the current being 1·0 to 1·25 amperes, the remaining volts being dropped in the series resistance. The lamp at this final stage operates in the region *e* of the current voltage curve shown in Fig. 1. The white-hot tungsten ball acts as a very intense point source of light suitable for projection purposes. The Pointolite lamp is a variant of this form, in which the discharge is initiated by means of a tungsten spiral heated electrically, the heating current being cut off when the lamp has started.

Obituary.

LIEUT.-COL. H. H. GODWIN-AUSTEN, F.R.S.

THE death, on December 2, of Lieut.-Col. Henry Haversham Godwin-Austen in his ninetieth year removes the last of the great pioneers in the geography of the Himalaya and a leading authority on Indian Mollusca. Col. Godwin-Austen was born at Teignmouth, July 6, 1834. He was a fellow-student with Lord Roberts at Sandhurst, whence they both went to India at the end of 1851. Godwin-Austen saw service the next year in the second Burmese War. His scientific tastes, which were hereditary—for his father, R. A. C. Godwin-Austen, was a geologist who has left an enduring reputation owing to his exceptional insight—led him in 1857 to join the Indian Survey Department. It was his privilege to survey northern Kashmir, where he discovered the Baltoro, Hispar, and Biafra Glaciers—the greatest group of valley glaciers in the world. They were afterwards traversed and mapped by Sir Martin Conway, who named the tributary glacier to the Baltoro from K_2 the Godwin-Austen glacier. The glaciers were described by Godwin-Austen in a short paper in the Proceedings of the Royal Geographical Society (vol. viii., 1864), the discussion on which is remarkable for Falconer's advocacy of the pre-glacial age of the Alpine lake basins and their preservation by the protective action of glaciers. During this survey Godwin-Austen fixed the position and heights of many of the giant peaks of the Karakorums, including K_2, which had been previously discovered by Montgomerie. It is often known as Mt. Godwin-Austen, and according to the heights adopted by the Indian Survey Department is the second highest mountain in the world.

While Godwin-Austen was working in this district he made many mountain ascents, of which his highest was on Mata, 20,600 ft., in 1862. In 1863–64 he was engaged in the survey of the eastern parts of the Himalaya around Darjeeling and in Bhutan, and, later still, further east on the Khasia Hills and in Assam. His views on the geographical structure and classification of the Himalaya were stated forty years ago in his presidential address to the Geographical Section of the British Association, which is his most important geographical paper. He contributed to the Geological Society several papers which made important additions to the geology of the Himalaya, including the discovery of the extension into Kashmir of the Spiti series, the most significant horizon in the Himalaya. In 1884 he described the drifts exposed in a new railway cutting near his home at Guildford, and the paper was illustrated by sections, characterised by the same precision and detail as those issued with his Indian papers.

After leaving the Indian Survey, Godwin-Austen's main interest was in the land mollusca. He was described as having "a unique knowledge of Indian molluscs." He contributed to "The Fauna of British India" the volume on the Testacellidæ and Zonitidæ. The value of his work on that group is shown by his election as president of the Malacological Society in 1897–9, and of the Conchological Society in 1908–9. His later years were burdened by financial embarrassment due to an unfortunately worded will. He inherited the paternal estate of Shalford, which proved a vampire instead of the source of a comfortable income. His interest was subject to fixed charges which, when the value of land fell, used up more than the whole of the income from the property. He bore this trouble with his characteristic courage and cheerfulness. Great sympathy was also recently felt for him, owing to the unfortunate loss of the portofolio of sketches and maps made during his Kashmir service, sixty years ago.

Godwin-Austen was elected F.R.S. in 1880, and received a belated Founders' Medal from the Royal Geographical Society in 1910.

HERLUF WINGE.

IT is with much regret that we record the sudden death, on November 10, at Copenhagen, of Herluf Winge, who for many years, and until his death, was "Viceinspektor" in the Zoological Museum of the University of Copenhagen. As a lad Winge began to study the small mammals of Denmark, and his earliest papers upon this subject were full of promise. A little later, in 1877, while still a student in the University of Copenhagen, he published an account of some of the skull characters in the mole, shrew, and other Insectivora, in which he displayed not only remarkable learning but a most clever technique. In 1882 he gave his views upon the mammalian dentition and his theory of cusp homologies in a paper which will ever be regarded as a classic. In the same year appeared an account of a collection of mammals from Greece; and in preparing this Winge was led so far afield investigating the relationships and special adaptations of the species before him that he himself regarded this piece of work as the foundation of the important publications next to be noticed.

Between 1887 and 1915 Winge published a series of works which ostensibly are descriptions of the fossil bones collected by Lund in the caves of Lagoa Santa, Minas Geraes, Brazil, and of the recent mammalia obtained in the same region by Lund and Reinhardt. Taking these mammals order by order (Rodents, 1887; Chiroptera, 1892; Carnivora, Primates, 1895; Marsupials, including Monotremes, 1897; Ungulates, including Sirenia, 1906; Edentates, 1915), Winge commenced each memoir with a description of the Brazilian material; but, that finished, he proceeded in each case to give a review of the whole order, bringing out his views of the evolution and relationships of the orders and of every fossil and living family and genus in a wonderfully clear and concise style. He seems to have prepared a complete monograph of each genus dealt with; and then to have compressed each monograph into a short paragraph and very often into a single sentence. But in this small space he contrives not only to state all that is essential, but to throw many a brilliant beam across what was previously obscure. Companion reviews of the Insectivora (1917) and the Cetacea (1919), the two orders not represented in the Lagoa Santa material, have since been published by Winge. That dealing with the Cetacea has recently been translated from the Danish by Mr. G. S. Miller

and published in the Smithsonian Miscellaneous Collections.

A collected and revised edition of these reviews, in three volumes, under the title of "Pattedyr-Slægter," is at present passing through the press; and the first volume of this work was received in London on the day before Winge's death. This new and more convenient edition will be welcome, for it is but bare justice to state that the reviews in question constitute together the finest, most comprehensive, and most inspiring technical account of the class Mammalia that has ever been written.

Many other papers dealing with the mammals of Greenland and the fossil mammals and birds of Denmark were published by Winge. In 1908 he contributed the volume on Danish Mammals to the series of handbooks entitled "Danmarks Fauna"; and this little book, illustrated by Winge himself, is at once admirable and inimitable.

Reviewing the whole of Winge's published work, one cannot fail to be struck by an extraordinary fact. It is that in his writings one does not mark the flight of time. He seems to have acquired his full mental power and his own peculiar way of looking at things at an extremely early age; for his early papers of 1877 and 1882 read to-day, exactly like that of 1919, as the work of a great master. M. A. C. H.

WE regret to announce the following deaths:

Prof. F. Clowes, emeritus professor of chemistry and metallurgy and first principal of University College, Nottingham, and the author of well-known text-books on analytical chemistry, on December 18, aged seventy-five.

Canon T. Wood, well known for his natural history studies, on December 13, aged sixty-one.

Current Topics and Events.

Two octogenarian fellows of the Royal Society celebrated their birthdays this week. Sir Archibald Geikie, O.M., the Nestor of British geology, who was elected to the Royal Society so long ago as 1865, attained the age of eighty-eight on December 28, and another distinguished geologist, Sir W. Boyd Dawkins, elected to the Society in 1867, was eighty-five on December 26. To both of them the congratulations of all scientific workers will be heartily accorded. Sir Archibald Geikie, who figured as a "Scientific Worthy" in NATURE thirty-one years ago (January 5, 1893), has a world-wide reputation. As a geologist, and as the author of the "Text-book of Geology," originally published in 1882, and of other standard works on geology and geography, he is known everywhere. This is in great measure due to the way in which Sir Archibald is able to quicken interest in his subject by the expression of his deep and intense feeling for Nature. No one has done more to link geology with appreciation of the natural beauty of scenery. His work as an original investigator in geology and as a writer of inspiring volumes on this subject and on physical geography won for him the Royal medal of the Royal Society in 1896. From 1908 until 1913 Sir Archibald served as president of the Royal Society, while he was president of the British Association at the Edinburgh meeting in 1892. For the period 1882–1901, he was Director-General of the Geological Survey of the United Kingdom and Director of the Museum of Practical Geology. In spite of his advanced age, Sir Archibald maintains his active interest in both science and literature, and so recently as 1918 he produced a notable volume of Memoirs of John Michell, who died in 1793, one of the early workers in geology.

SCIENTIFIC societies and other bodies organising conferences for next year should know that the authorities of the British Empire Exhibition to be held at Wembley have constructed an admirable congress building containing four conference halls, with appropriate committee rooms, etc., capable of seating 2140, 550, 180, and 150 persons respectively. These halls are being allocated to responsible organising committees free of charge, and early application should be made for the use of any of them, as the dates are being filled up rapidly. The following scientific and technical societies, among others, have already booked one or more of the halls for conferences on different dates: The British Engineers' Association, the British Electrical and Allied Manufacturers' Association, the Institution of Sanitary Engineers, the Textile Institute, the Society of Dyers and Colourists, the North-East Coast Institution of Engineers and Shipbuilders, the Institution of Automobile Engineers, the Museums Association, the Horace Plunkett Foundation, the Health Propaganda Association, the Association of British Chemical Manufacturers, the Institution of Mining and Metallurgy, the Municipal Electrical Association, the Electrical Contractors' Association, and the Gas Association. Applications for use of the halls on dates still open should be sent to the Secretary, Conference Committee, British Empire Exhibition, 16 Grosvenor Gardens, London, S.W.1.

WITH the approaching retirement of Prof. S. Alexander from its chair of philosophy, the University of Manchester loses the services of one of the most original of the elder generation of thinkers. Nearly fifty years ago, he came from Australia to Oxford, where he gained reputation by a rare power of winning first classes. He soon, however, deserted other pursuits for philosophy, and won an assured position before he was thirty by his remarkable book on "Moral Order and Progress." Called in 1893 from a tutorship at Lincoln College to succeed Robert Adamson at Manchester, he has represented philosophy there for more than thirty years. At Oxford he was conspicuous in the reaction against the philosophy of T. H. Green, and was among the first to preach to an unheeding university the importance of modern psychology. But he never lost a bent for metaphysics and for vigorous thinking about fundamentals. His philosophic position was fully revealed in his Gifford lectures at Glasgow on "Space, Time, and Deity," published in 1920. A book so technical defies

analysis, and it is enough to say that, though many disagreed with his doctrine, there was an absolute consensus among experts that it was a contribution of the first importance to philosophic thought. Yet few philosophers have lived less in the clouds, and Alexander has not only discharged meticulously the duties of an exacting chair, but has also been prominent in many university and public activities. Ever a keen champion of the higher education of women, he took a foremost part in the foundation of Ashburne Hall, the women's hall of residence, the secretaryship of which he is resigning on his retirement from university life.

THE first part of the funeral service for Canon T. G. Bonney was held in the Chapel of St. John's College, Cambridge, on December 12. Among those present were the following fellows of the Royal Society: Prof. A. C. Seward and Prof. J. E. Marr (Geological Society), Mr. C. T. Heycock (Cambridge Philosophical Society), Prof. E. J. Garwood (Alpine Club), Sir Clifford Allbutt, Prof. H. F. Baker, Mr. F. F. Blackman, Sir Joseph Larmor, Dr. G. D. Liveing, Sir Ernest Rutherford, Prof. W. T. Sollas, Sir Joseph Thomson, Prof. W. W. Watts, and Prof. J. T. Wilson.

THE Council of the Royal Meteorological Society has awarded the Symons gold medal for 1924 to Dr. Takematsu Okada, Director of the Central Meteorological Observatory, Tokyo, Japan. The medal is awarded for distinguished work in connexion with meteorological science, and will be presented at the annual general meeting on January 16.

THE discussion before the Illuminating Engineering Society on December 11 was concerned with a problem that confronts many of those who are associated with applied science—the best method of disseminating technical information amongst the general public. Illumination involves an appeal to the eye, and influence is best brought to bear through the medium of actual demonstrations of good and bad methods of lighting. Details of actual experience in practice, for example, of improved output and greater freedom from accidents resulting from better lighting, are also of great value. But in order to be convincing, such data must be derived from scientifically conducted tests and backed by recognised authority. Mr. Dow mentioned some of the work which the Society is doing in this connexion—for example, in co-operation with representatives of the printing trade and with the British Industrial Safety First Association. A considerable part of the discussion was devoted to the question of the high values of illumination now being advised in some quarters. The view was expressed that such recommendations must be based on scientific method, and that the desired conditions are best ascertained by experiments conducted with the aid of leading industrial councils. This same point also came up for consideration in a discussion initiated by Mr. W. P. Fanghaenel and Mr. W. N. Booth before the Institution of Civil Engineers on December 12, when Mr. L. Gaster explained the procedure of the Home Office Departmental Committee concerned with industrial lighting and emphasised the distinction between values desirable in practice and legal minima.

IN order that donors might have the opportunity of seeing the premises and the equipment of the Department of Glass Technology at the University of Sheffield, a series of luncheons have been arranged, the first having been given by Mr. W. F. J. Wood, chairman of the Glass Research Delegacy, on November 15, and the second of the series by Prof. W. E. S. Turner, president of the Society of Glass Technology, on December 13. The new premises, which cover three-fourths of an acre, were, until the end of 1920, in occupation as an actual glass works. Since being purchased at a price of 9000*l.*, considerable alterations have been made, a set of laboratories and small library constructed, whilst the other buildings have been adapted and equipped with plant for experimental glass melting. In this connexion there are furnaces capable of melting glass on any scale between a few grams and about 120 lb., the firing being by town's gas and compressed air, whilst a large two-pot recuperative furnace fired by oil has a capacity of two pots each of about 15 cwt. There are, in addition, a block of buildings devoted to the making of all sizes of clay pots, store rooms for the glass-making materials, a room for mixing, a machine room, smith's shop, compressor house, etc. Courses of instruction lead to the degree of B.Sc.Tech. and higher degrees. In addition, however, to the normal teaching work of the Department, a great deal of experimental work has been done for individual manufacturing firms, whilst since 1917 no fewer than 96 papers involving research have been published from the Department. The Department has no endowment, but the glass industry has been very appreciative of the work done and has contributed generously towards its maintenance.

MR. T. W. T. TUCKEY, who was in Japan at the time of the great earthquake, had an opportunity shortly afterwards of visiting both Tokyo and Yokohama, and gives the results of his observations in *Engineering* for November 30. The framework of the ordinary Japanese house is made of very light uprights secured, by tenons only, to other light horizontal members at the floor and ceiling. The floors and ceilings are wood, and the inside divisions are of wood and paper. When a severe shock causes the tenons to break, the structure closes up and pins down any occupants who do not escape quickly. The charcoal fires are also pinned and thus fires are started. It is almost inconceivable that up to August 31, 1923, such buildings were still being constructed in the capital city of Tokyo. Temples are also built of wood and have nothing but horizontal and vertical timbers in their construction; the timbers, however, are very massive, and such buildings stand up well against earthquakes and storms. In Tokyo, the first brick buildings of any importance were put up by the Government; nearly all these buildings survived the shock, though a few were burned. It will be remembered that the fires, started by the collapse of the more flimsy buildings, destroyed a large part of Tokyo. Tokyo station

building, three and four stories high and some hundreds of feet long, constructed of red brick, was not damaged by either earthquake or fire. Reinforced concrete buildings in Tokyo did not come off so well as the better-class brick buildings. Much of the brick facing has come away and there are cracks in the concrete. They are, however, probably the safest buildings for the inhabitants, and office buildings of this class have continued in use without interruption. The behaviour of steel frame buildings was peculiar; from a few feet above the ground the brickwork is cracked, and this continues for two or three stories. Above the third and up to the top (in some cases eight stories) no damage whatever is to be seen. The writer was nowhere able to find the slightest sign of failure of the foundations of any building, whether wrecked or standing.

THE report for 1922 of the director of the Bernice Pauahi Bishop Museum at Honolulu has recently been issued. It gives a summary of the various activities of the Museum officials in researches relating to the natural history of the Pacific Islands and the culture and folk-lore of the Hawaiians and other Polynesian people. A number of expeditions for systematic survey in anthropology, botany, and zoology have been undertaken in connexion with the Museum. The most important were the Whitney South Sea expedition, an expedition to Fanning Island, the exploration of Guam in the Ladrone Islands, and the Bayard Dominick expedition for the investigation of the origin, migration, and culture of the Oceanic people. Some interesting general conclusions have been reached by the members of the Dominick expedition with regard to the Polynesian population. There seem to be two basic elements. The first is Caucasian with physical characteristics approaching some Mongols, with tall stature, moderately long heads, relatively high narrow faces and noses, light brown skin, and straight or wavy black hair. The second element is the Indonesian typical of Celebes, with shorter stature, low broad faces, wavier hair and darker brown skin. A third element is found only in small numbers with very short heads, narrow faces, and light skin. The second type is characterised by a higher social and religious development than the first. The first type is universally distributed in the Pacific, but strongest in New Zealand and the Marquesas. The second type is prevalent in North and Central Polynesia. In the report Mr. J. F. Illingworth notes that the Hawaiian house-fly is not the same as that of Europe and the United States, but is a variety found on the western shores of the Pacific. As it is known that these flies follow man, and there were house-flies in Hawaii when Captain Cook arrived, the inference is drawn that the original immigrants and the flies came to Hawaii from the west.

APPLICATIONS are invited by the secretaries of the Royal Society for the Armourers and Brasiers' Company research fellowship in metallurgy, tenable in the first instance for two years, with a possible extension to five years. The research undertaken by the successful candidate must be connected with base metals and alloys, preferably those used in the ancient crafts of the Company of Armourers and Brasiers. The annual value of the fellowship is 500*l*. Applications must reach the secretaries of the Royal Society, Burlington House, W.1, by March 1 next.

WE have received the annual report of Livingstone College, Leyton, for 1922–23, being the thirty-first year of its existence. The College gives courses of instruction with the object of teaching missionaries how to care for their own health, and how to deal with the diseases of the people among whom they are working, when far from qualified medical aid. Altogether 752 students have passed through the College. Donations and subscriptions are requested to help carry on this useful work.

THE ninety-second annual meeting of the British Medical Association will be held on July 18-26, 1924, at Bradford, under the presidency of Mr. J. Basil Hall, consulting surgeon to the Royal Infirmary, Bradford. The presidential address will be delivered on July 22. The following presidents of sections have been appointed:—Medicine: Prof. A. J. Hall; Surgery: Sir Cuthbert Wallace; Obstetrics and Gynæcology: Mr. J. S. Fairbairn; Pathology and Bacteriology: Prof. C. H. Browning; Neurology and Psychological Medicine: Dr. T. G. Stewart; Ophthalmology: Dr. A. M. Ramsay; Public Medicine and Industrial Diseases: Mr. H. Jones; Diseases of Children: Dr. L. Findlay; Laryngology and Otology: Dr. W. J. Horne; Orthopædics: Mr. R. C. Elmslie; Medical Sociology: Mr. A. Manknell; Dermatology: Dr. J. MacL. H. MacLeod. The honorary local general secretary is Dr. W. N. West Watson (Victor Lodge, Manningham, Bradford).

THE Seismological Society of America has published a large Fault Map of the State of California (three sheets and a title-sheet) on the scale of 1 : 506,880, or close on one inch to eight miles. The topography is based on various official surveys, the hills being well brought out by a system of colour-shading. The sea-depths are shown by contours drawn at intervals of 100 fathoms. The known and probable faults, which mean so much in the moulding and instability of the continental edge, are marked by lines of various colours; these are broken where details are uncertain or inferred. A fault indicated as "active" is usually one along which an earthquake has occurred during historic time. The mind of the world has been once more riveted on the uncertainties of the Pacific ring, and this map, which must be mounted as one wall-sheet for its proper appreciation, will no doubt find a permanent place in colleges that respect geography. Prof. Bailey Willis has furnished a lucid description to accompany the sheets (Bull. Seism. Soc. America, vol. 13, No. 1, 1923).

A REPORT by the Meteorological Department of the Government of India for 1922–23 has just been issued under the superintendence of Mr. J. H. Field, the officiating Director-General of Observatories. The policy of Indianisation has been adopted, and the personnel for the thirteen posts of meteorologists has changed from 10 Europeans and 3 Indians in 1919 to

3 Europeans and 10 Indians in March 1923. A study of upper air movements in India is said to be laying the foundation for types of forecasting not hitherto possible from surface observations. The whole system of warnings for storms and cyclones over the sea and on land throughout India is the duty of the headquarters staff, and all is now done from Simla. Considerable retrenchment has been made during the year, which has involved the partial stoppage of Bombay, Madras, and Calcutta Daily Weather Reports, the issue being suspended during the seasons of least rainfall. Shipping at sea is supplied with the latest information regarding the weather by wireless bulletins. Upper air research shows that at heights of 4 miles and upwards the cold weather winds of northern India often reach a strength of 100 miles per hour or more, while calms prevail at the surface. At Agra the westerly components of upper air, at a height of about 4 miles, prevailing from the middle of September to the middle of October, show a close relationship with the precipitation in north-west India in the winter following. Departmental observatories for the year consist of 5 first class, 185 third class, 23 fourth class, and 24 fifth class. Rainfall observations are received from 2926 stations.

MESSRS. HAWKSLEY AND SONS, 83 Wigmore Street, W., have forwarded to us their catalogue of medico-diagnostic, physiological, anthropometrical, psychological, and chemical apparatus. Several forms and sizes of capillary pipettes for the accurate measurement of quantities from 0·005 c.c. to 1·0 c.c. are listed, as well as several types of hæmacytometers and hæmoglobinometers for the estimation of the number of corpuscles and amount of hæmoglobin in blood. Under blood analysis apparatus we find outfits for the estimation of calcium, urea, and sugar in the blood. Galton's finger-print outfit and whistle and many pieces of anthropometric and psychological apparatus are catalogued. Messrs. Hawksley are also agents for the microscopes and accessories of the Spencer Lens Co., New York.

IN the "Fauna of British India" Series the further volumes which the editor, Sir Arthur E. Shipley, with the assistance of Dr. Hugh Scott and with the sanction of the Secretary of State for India, has arranged for are: volumes on Butterflies (Lycænidæ and Hesperiidæ) by Mr. N. D. Riley; on the Ixodidæ and Argasidæ by Prof. G. H. F. Nuttall and Mr. C. Warburton; on Leeches by Mr. W. A. Harding and Prof. J. Percy Moore; on the Curculionidæ by Dr. G. A. K. Marshall; on the Carabidæ by Mr. H. E. Andrewes; on the Meloidæ by Mr. K. G. Blair; on the Erotylidæ and Endomychidæ by Mr. G. J. Arrow; on the Culicidæ by Capt. P. J. Barraud, Major S. R. Christophers, and Mr. F. W. Edwards; on the Chrysomelidæ (subfamilies Chrysomelinæ and Halticinæ) by Mr. S. Maulik; on the Scolytidæ and Platypodidæ by Lt.-Col. Winn Sampson; together with a revised edition of Mammalia by Mr. Martin A. C. Hinton and Mr. R. I. Pocock, and of Birds (6 vols.) by Mr. E. C. Stuart Baker.

THE latest catalogue (New Series, No. 10) of Messrs. Wheldon and Wesley, Ltd., 2 Arthur Street, W.C.2, should, we think, be very useful to librarians and others, it being a classified list of some 840 serials and transactions of scientific societies on sale by them. The catalogue is conveniently arranged under the headings: British Isles—Transactions of societies and other scientific periodicals; British Isles—Proceedings of local societies; Dominions and Colonies—scientific serials, etc.; United States of America—scientific serials, etc.; and foreign countries—scientific serials, etc.

Our Astronomical Column.

THE JANUARY SHOWER OF METEORS.—This display of meteors is of greater importance than is supposed. It sometimes furnishes a rather brilliant exhibition of a conspicuous character, being more brilliant than the average and traversing longer paths. The radiant point is situated at about 230° +53° in the region barren of bright stars lying on the borders of the constellations Boötes, Draco, and Hercules.

The shower has occasionally been so abundant as to furnish one or two meteors per minute. In the evening hours, from the latitude of England, the radiant point is situated at a low altitude in the northern sky, and it is generally in the few hours preceding sunrise that the display attains its greatest strength. Unusually rich returns of these meteors were witnessed in the early evening hours of January 3, 1918 and 1922, and we may expect another plentiful exhibition of its meteors on the morning of January 4 next between about 4 and 6 A.M. The moon will not offer any obstruction on that date, as it will be 26 days old and visible as a very narrow crescent only.

Should the weather be clear on the morning of January 4, all the conditions are promising for a meteoric spectacle of very interesting character, and it will be important to observe it carefully through the night in order to determine the hourly number of meteors visible and the time when it reaches a maximum.

THE AXIS OF MARS.—*Popular Astronomy* (November) contains an interesting study by Prof. W. H. Pickering of the position of the axis of Mars. He notes that the method used by Lowell of observing the polar caps is subject to a systematic error. The edge of the cap has a sensible diurnal shift: the white deposit melts on the noon side of the cap, and forms again on the opposite side. Accordingly a new determination was made, based on a large number of small well-defined markings spread over the disc. Incidentally the conclusion was reached that a large number of the Martian spots have a sensible annual shift, easily explicable on the view that they are vegetation phenomena. This, however, can be eliminated from the discussion. Prof. Pickering's final value for the obliquity of the Martian equator to its orbit is 24° 14′, a degree greater than Lowell's. He gives for the co-ordinates of the point to which the N. pole is directed—

$$\text{R.A.} = 20^h\ 58^m\ 6^s + 1{\cdot}56^s\ (t-1918)$$
$$\text{N. Decl.} = 52^\circ\ 12'\ 50'' + 12{\cdot}6''\ (t-1918).$$

The equinox of the planet is shifted back 7·16° from 87·89° to 80·73°. This has the effect of increasing the Martian date by 14 days. The method employed seems to give this determination more weight than any other that is based on markings on the disc.

Research Items.

THE CAVE OF MACPELAH.—In the concluding issue for the year of *Ancient Egypt*, Sir Flinders Petrie discusses the probable position of the double cave below the Herodian monument which is described in the lately published "Hebron, le Haram el Khalil," by Père Vincent and Captain Mackay. Owing to the fanaticism of the present Arab population, the authors of this work were not allowed access to the subterranean parts. Our knowledge of these is derived from an account, written in A.D. 1136, of an examination of them in A.D. 1119 by the monks. Sir Flinders Petrie's conclusion is that the double cave probably lies to the S.E. rather than to the N.E. of the basilica-like chamber to which the monks penetrated. A point of interest in connexion with the superstructure is that while the internal proportions indicate the Jewish foot as the unit, those of the exterior conform to the Roman foot, the design being based on the fact that the two units can be worked together on a ratio of 10 : 11 in the length or 11·5 : 12·5 in the breadth.

ROCK PAINTINGS IN PAPUA.—Dr. W. Mersh Strong has published in the December number of *Man* photographs and tracings of a number of rock paintings from the Central District of Papua. They were found on a prominent whitish rock, and were executed in a single monochrome red, apparently a preparation of iron oxide. The designs included a cassowary, a figure of a man, a scroll pattern, a double chevron with pendent lines, possibly a tortoise, a man's face, a crescent, and a hand. There is nothing to indicate their age except that they are covered with a slight film, probably of calcium carbonate derived from the trickling of water. The present natives have no knowledge as to who did them. Dr. Strong is of the opinion that the face design suggests the face *motif* of the Papuan Gulf, but points out that this culture has its centre some two or three hundred miles west of Port Moresby and scarcely comes within a hundred miles of that area. He also refers to the paintings of canoes and men in red monochrome seen by Seligman in the Marshall-Bennet Islands.

THE COPPER ESKIMO.—Two further instalments of the Report of the Canadian Arctic Expedition 1913–1918 have just been issued; these are "The Physical Characteristics of the Copper Eskimo," by D. Jenness, and "The Osteology of the Western and Central Eskimo," by John Cameron, being parts B and C of volume xii. The measurements given by Mr. Jenness were, for the most part, taken at Coronation Gulf, where the expedition spent two years. Mr. Jenness concludes that there is strong support for Boas's view that Indian admixture in Alaska has increased the stature and produced a marked tendency towards brachycephaly; and that while the Copper Eskimo show more resemblance to the Eastern Eskimo than to the Alaskan, they differ from most other Eskimo in that the head is slightly longer and broader, although the cephalic index is virtually the same as among the pure-blooded tribes to the eastward. It is interesting to note that Mr. Jenness finds no evidence to support Dr. Stefansson's theory of European admixture among the Copper Eskimo. Of the features principally relied upon by Dr. Stefansson, Mr. Jenness holds that the proportion of face breadth to head breadth is illusory, and the blue or grey tinge of the eye is pathological in origin and common elsewhere.

CAUSAL ORGANISM OF POTATO BLACKLEG.—As the result of a study of twelve strains of the potato blackleg parasite, including the four "species" originally described as the cause of the disease, H. M. Jennison concludes, in a paper published in the Annals of the Missouri Botanical Garden, vol. x. No. 1, February 1923, that the blackleg disease of Irish potatoes in North America and Europe is caused by a Schizomycete which should bear the name *Bacillus atrosepticus* van Hall. The following names are to be considered only as synonyms: *Bacillus phytophthorus* Appel, *B. solanisaprus* Harrison, *B. melanogenes* Pethybridge and Murphy. The pathogen infects the stems and the tubers of the potato. Virulence of the parasite, as tested by artificial inoculation, appears to be dependent upon a rather delicate balance of temperature and water relations, and upon the sugar content of the tissues inoculated.

CYTOLOGY OF MUTATION.—Prof. R. R. Gates has an important paper in the *Annals of Botany*, vol. xxxvii. No. 148, October 1923, under the title "The Trisomic Mutations of Œnothera," in which he describes the occurrence in the F_1 generation of the cross *Œnothera rubricalyx* × *Œ. Hewettii* of a mutant with fifteen chromosomes, and discusses in connexion therewith the whole question of the chromosome mechanism associated with such types of mutant. In Œnothera, relatively few mutants are found with fourteen chromosomes; these may be accounted for in terms either of crossing over or of double "non-disjunction." "Non-disjunction" has been called in to explain the existence of the relatively frequent trisomic mutations (with 15 or 16 chromosomes). It is assumed that on segregation two chromosomes of a pair, instead of separating to different gametes, both go into one cell; thus in a pollen tetrad two pollen grains will be found with eight chromosomes each instead of seven. When, as in the mutation now described by Prof. Gates, two precisely similar mutants appear in a small culture, it would seem probable that both such pollen grains have functioned, so that the male parent is responsible for the extra pair of chromosomes. Inevitably in discussing such a problem the question arises as to what extent the seven pairs of chromosomes in Œnothera may be regarded as individually distinct. Prof. Gates discusses the question in a tentative manner, directing attention to recent statements by Hance (1918) and Van Overeem (1922), who conclude that these seven pairs are distinct and form a graded series. Prof. Gates is evidently of opinion that this conclusion is not yet sufficiently soundly based upon observation and experiment, but that the cytological complexities of the problem well deserve further exploration.

DISTRIBUTION OF HERRING SHOALS.—The report of the Dove Marine Laboratory, Cullercoats, for 1922–23 contains an interesting paper by Mr. B. Storrow on the distribution of herring shoals. Evidence is given in favour of the view that the failure of the industry in 1921 was due, in part, to a migration of young North Sea herrings in the preceding winter. Late in 1920 these fish divided into two sections, one of which migrated northwards towards the Orkneys and Shetland, and the other southwards. The northern group thereby passed into an area favourable to growth, and grew rapidly. The southern section grew much less rapidly. If this be so, the herring industry in any particular locality should depend upon whether the herring caught are migrants from a region of rapid or of slow growth, rather than upon the existence of a particular year class. The author is inclined to the view that migrations, which may in some cases depend upon the "activity" of Atlantic

water, prohibit the existence of different herring races in the North Sea.

EUCALYPTUS OILS AS GERMICIDES.—Messrs. A. R. Penfold and R. Grant give an account of an investigation of the germicidal values, determined as Rideal-Walker carbolic acid coefficients, of the principal commercial eucalyptus oils and of their active constituents (Journ. and Proc. Roy. Soc. of N.S. Wales, vol. lvii., 1923, p. 80). Standard suspensions of 1 per cent. of the crude oils and their pure constituents were made in 7½ per cent. resin soap solution. Of the oils of ten species of Eucalyptus, that of *E. radiata* was the strongest and gave a coefficient of 10-12, the active principle being piperitol. Of active principles, australol, geraniol, citral, and piperitol gave coefficients of 22·5, 21, 19·5, and 13 respectively. The interesting observation is made that a lower coefficient is given by the dilution (with water) of a concentrated preparation than by a dilute preparation of the same strength, probably because the dilution of a concentrated emulsion upsets the emulsion.

RED DISCOLORATION ON DRIED SALTED FISH.—The condition known as "pink" is one to which dried salted fish is liable, and is characterised by the appearance of pink patches on the surface. It is dealt with in Special Report No. 18 of the Food Investigation Board by Dr. P. C. Cloake. These pink patches are caused by the growth of chromogenic micro-organisms of at least two species—one a red sarcina, the other a curiously polymorphic form which may be a bacillus. These organisms may be cultivated on such media as salted fish agar, provided they contain a high percentage of salt, *e.g.* 15 per cent., at a temperature of 24° C. The source of these organisms has been traced to the salt used in curing when this is of marine origin; rock salt seems to be free from them. Sterilisation of the salt at 120° C. for 30 minutes suffices to destroy the organisms.

A SUGGESTED INDICATOR FOR PETROLEUM.—In the Journal of the Royal Society of Western Australia, vol. 9, p. 8 (1923), A. Farquharson describes an occurrence of the hydrocarbon impsonite, infilling the vesicles of a basalt that underlies a limestone variously regarded as of Cambrian or Lower Carboniferous age. Specimens have been collected from various points in the Ord Valley near Kimberley, West Australia, and these were sent to the office of the Geological Survey in the first instance as possibly oil-bearing shales. The author points out that the occurrence is of sufficient magnitude to have a bearing on the search for petroleum in the district. We need not share his view (p. 17) that oil would be unlikely to occur if the rocks were of Cambrian age, since seepage from a distance is always possible, and the highly vesicular character of the basalt may have provided a favourable storehouse on the way. As E. H. Cunningham Craig remarks, migrating petroleum will make its appearance in "the most porous rock available."

CLIMATIC CHANGES AND WEATHER NORMALS.—The U.S. *Monthly Weather Review* for August contains an article by Prof. C. F. Marvin, Chief of the U.S. Weather Bureau, on the above subject. The discussion is introduced by a question, "Is the climate changing?" and justifies the answer of "Yes" or "No" to this inquiry. Geological records are said to leave no question as to the great changes the vast lapse of time has occasioned in the past, while there is said to be no conclusive evidence of notable permanent changes during thousands of years of human history. The author believes that long-time fluctuations of climatic conditions have occurred, and that minor surgings of the seasons to and fro take place for such periods as 50 to 100 years. Reference is made to the somewhat general deep-seated conviction that, to many, weather conditions at the present time differ from corresponding conditions within their memory. The prime object of the discussion is to establish a method of completing a broken record of observations, say of temperature or rainfall, so as to lengthen out to the utmost a series of observations and thus to secure long-period normals of observations to aid in obtaining proof of secular changes if such are obtainable. A method is suggested for completing the individual values for missing years which is practically a system of drawing lots from the values of all the years for which observations exist, and so on for all the years for which means are required. This system scarcely seems likely to commend itself to all workers. Considerable importance is attached by the author to the use of accumulated sums of departures from a normal base and exhibiting the same as a graph.

PHOTOELECTRIC CELLS FOR MEASUREMENTS OF TIME.—In the *Comptes rendus* of the Paris Academy of Sciences, November 5, 1923, Messrs. G. Ferrie, R. Jouart, and K. Mesny describe methods employed to amplify the current from a photoelectric cell, so that the amplified current can be used to record the passage of a pendulum through a certain point of its path. The anode of the photoelectric cell was joined to the grid of a special triode valve, and the filament of the valve to the positive of a battery, the negative of which was connected to the deposit of alkali metal in the cell; a constant high potential difference was applied between the anode plate and the filament of the valve. When the cell was illuminated, the grid was charged negatively, and the current of the valve was diminished. In this way a variation of current, 10,000 times as great as the original photoelectric current, can be obtained; and, by attaching to a pendulum a screen, provided with a slit, through which light from an electric lamp can pass, measurements of the time of vibration can be made with considerable accuracy. With a more complicated arrangement of valves, an amplification of the order 10^6 was obtained and it was possible to determine the period of the pendulum within one-thousandth of a second. The authors hope to be able to adapt the method for recording the passage of stars across the central line of a meridian telescope.

VELOCITY DISTRIBUTION OF ELECTRONS FROM INCANDESCENT OXIDES.—The velocity distribution of the electrons ejected from incandescent substances has been investigated by the integral method, not attempting to separate out the electrons moving at or near a definite velocity, but deducing the distribution law from observations which included all the different velocities present; Richardson used also the differential method. All the observers have found that Maxwell's probability law for the distribution of the velocities is correct in the case only of clean metal surfaces. In the *Zeitschrift für Physik*, November 15, 1923, Herr M. Rössiger describes experiments, using the differential method, in which the electrons pass through a longitudinal slit, parallel to the axis of the cylindrical anode; this is coaxial with a straight, incandescent platinum wire which forms the cathode and is coated with oxides of calcium, barium, or strontium. There is an outer cylinder, coaxial with the first, and electrically connected with

it; in this is a slit, parallel to that in the surface of the inner cylinder, while outside this slit, and insulated from the cylinder, is a collecting plate, which receives the electrons which pass through both slits. The inner cylinder can be rotated about its axis; so that the angle ϕ between the planes passing through either slit and the cathode wire can be varied, and measured by means of a reflecting mirror. A solenoid is wound round the cylindrical glass containing vessel, so that a magnetic field can be produced in the direction of the axis of the cylinders, deflecting electrons with a certain velocity which pass through the first slit, so that they pass through the second when ϕ has the correct value. Maxwell's law is still found to hold.

MAGNETIC SURVEY OF THE BALKANS.—Heft 10, Bd. 131, Abt. IIa, Math. Nat. Kl. of the Sitzungsberichte of the Vienna Akademie der Wissenschaften contains a paper by Mr. A. Schedler, which gives the results of a magnetic survey carried out during 1918 in the Balkans. Results are given for 27 stations, varying in latitude from 44° 49′ to 40° 55′ N., and in longitude from 18° 32′ to 21° 55′ E. Attached to the paper are six charts. The first and the last indicate the geographical positions of the stations, and the geological features of a magnetically disturbed region. The four intermediate charts give curves of equal values of magnetic declination, inclination, horizontal force, and total force respectively for the epoch January 1, 1918. Through an oversight, the values of the force are printed as angles in the charts. For example, 0·4444 C.G.S. is printed as 44° 44′. It is interesting to note that the dip observations were taken with an English dip circle, Dover No. 1.

INVERTED FLIGHT IN AEROPLANES.—A paper of considerable interest to practical aviators, as well as to workers in the dynamics of aeroplane flight, was read recently before the Royal Aeronautical Society by Squadron Leader R. M. Hill. The paper is entitled "The Manœuvres of Inverted Flight," and is based upon extensive experimental flights executed by Mr. Hill and others. The object of the experiments was threefold. The immediate aim was to examine the causes of fatal accidents that often occur in aerobatics on an unstable aeroplane, when the aeroplane assumes an inverted position and the pilot fails to right the machine. Subsidiary aims were to find the magnitudes of the loads in inverted flight, and to examine the behaviour in inverted flight of machines with different stability characteristics. An account is given of the ways in which inverted flight can be obtained, namely, by means of the half loop and the half roll, and details of the manœuvres are given for particular aeroplanes, such as the Sopwith "Camel," the "Camel" modified so as to increase its longitudinal stability, the "Snipe," the "Bat Bantam," and the S.E.5A. The use of the controls in inverted flight and the return to normal flight are similarly discussed. Mr. Hill considers the belting arrangements to be of supreme importance, especially in unstable fighting machines; pilots often fail to use the controls because they cannot reach them. Steady inverted flight is possible on all types of machines investigated; but whereas the longitudinally stable machine tends to right itself, the longitudinally unstable machine has no such self-righting properties: there is, however, no real difficulty in recovering from the inverted flight. The longitudinally unstable machine is also liable to get into an inverted spin, but here again the pilot can recover if he knows the use of the controls in such positions. Inverted loops were also investigated. Mr. Hill suggests that "the best compromise between safety and extreme manœuvrability is to be found in an aeroplane which, though preferably stable throughout the major part of its range of flying speeds with elevators free, must definitely be stable with them fixed."

SILICATE OF SODA FOR THE TREATMENT OF CONCRETE ROADS.—Silicate of soda is now being more and more used in Great Britain for the surface treatment of concrete, following on the extensive and very satisfactory experience recorded in America. In fact, new uses for silica of soda are being found almost every day, and this material looks like rivalling sulphuric acid, soap, or soda ash as a ready test, according to the amount consumed, for the civilisation of a community. The chemical reactions that result from the application of a dilute solution of silicate of soda to concrete, say the surface of a road, are very complicated, but seem to include the combination of the silicate with the free hydrated lime liberated in the setting of cement to give a lime silicate, which forms a hard compound. At any rate, the nett result is the formation of an intensely hard outer skin—in which all the pores have been completely filled up—strongly resistant to abrasion and dusting, and largely waterproof. It is essential, however, that the silicate of soda be sprayed over the road in the form of a very dilute solution, say 1 of the liquid neutral silicate to 4 of water, whilst the silicate of soda must be prepared for the specific purpose, with a fairly high ratio of silicate to soda. As is well known, very many grades are supplied, from a low-ratio product containing 1·60 molecules silica to 1·00 molecules soda (Na_2O) to a very high-ratio grade with over 4·0 molecules silica. The right brand to use is a matter of experience and research on the part of the firms supplying the product, but the results, under proper conditions, are remarkable, and constitute a factor of national importance in the upkeep of roads.

TESTS ON BOILER MATERIAL.—The annual memorandum by Mr. C. E. Stromeyer, Chief Engineer to the Manchester Steam Users' Association, covering the year 1922, contains several interesting matters. Tests have been made on the material of some old wrought-iron boilers, one of which was sixty-nine years old, and a comparison with the tests of the original material shows that wrought iron does not lose tenacity appreciably with age. The furnace plates show a reduction of ductility, but not of tenacity. Mr. Stromeyer again directs attention to the effect of nitrogen on mild steel, and urges that the effect of a high proportion of this element, such as is found in Bessemer steel, requires more thorough investigation. A table of failures of mild-steel plates, bolts, stays, and rivets is given, 22 in number, and in every case the sum of $5N+P$ is greater than 0·08 per cent., the upper limit previously fixed by the author. A case for inquiry has been made out, and it is to be desired that analyses for nitrogen should be made more frequently, until its alleged harmfulness has been confirmed or disproved. The tests on riveted joints in old boilers show that the strength of a double-riveted seam in a boiler is greater than that found when the seam is cut out and the joint tested in a machine, so that the engineering practice of crediting the joints with their full strength is justified. An interesting section on dished and flat-end plates of boilers deals with the behaviour of cracks, which in some cases do not spread, but relieve the stress, so that some boilers mentioned worked for years in a cracked condition. This is traced to a very finely laminated structure in the outer layers of the plates.

The Jubilee Celebrations of the French Physical Society.

IT was in 1873 that the Société Française de Physique came into being, and the first volume of the Proceedings of the Society contains a report by Lissajous on the preliminary steps that were taken. The statutes include one by which any discussion "étrangère à la physique" is prohibited. Whether the French physicist of fifty years ago was a keen politician we do not know, but it seems to have been desirable to provide against extraneous matters more rigorously than is our wont in Great Britain.

A glance at the first list of members reveals a number of very well-known names, such as the Becquerels, Berthelot, Bouty, Cornu, Jamin, Joubert, Koenig, Lippmann, Lissajous, Mascart, Sainte-Claire Deville, and Violle. The first president was Fizeau, and the following eight successive presidents were Bertin, Jamin, Quet, E. Becquerel, Blavier, Berthelot, Mascart, and Cornu. The first honorary member was the elder Becquerel. In 1876 there were five honorary members, including Regnault and Sir William Thomson; and in 1878 the names of Fizeau and Joule were added.

In the early part of this month, the founding of the Society was celebrated by a number of meetings. Apart from these there has been the Exhibition, which has hitherto been held by the Society at Easter, but has this year been combined with a Wireless Exhibition. It has been on an unusually large scale, as may be realised when it is said that the Grand Palais in the Champs Élysées, in which the annual Automobile Show is held, was used for the purpose. The Exhibition was excellent from many points of view, and was characterised by many demonstrations, more or less popular, which were very attractive.

The anniversary lectures were given at the Sorbonne, the first on Saturday, December 8, by Col. Robert, on the relations of physical and technical aeronautics.

On Monday morning, December 10, an attraction of another kind presented itself in the general meeting of the International Union of Physics. The chair was taken by M. Brillouin with Prof. H. Abraham as general secretary. The business was largely formal, the main item being the adoption of the statutes. After some discussion as to whether the value of the franc for the contributing countries should be taken in the French or Swiss currency, the former was adopted, notwithstanding the reduction in the contributions by so doing. The date of the next meeting of the Union was fixed for the year 1925, the normal three years' interval being reduced, and the question of an international congress will then be decided. A somewhat pious resolution was adopted on the desirability of authors supplying abstracts to their papers, such abstracts being left in the hands of the editor of the journal concerned for final revision. The meeting was followed by a luncheon.

On Monday evening a lecture was given by Prof. H. A. Lorentz on the old and new mechanics. The motion resulting from the impact of two balls was considered, and generalised equations were obtained which were applicable to two observers in relative motion. This was followed by the gravitational deflexion of light, and a discussion of the quantum theory and kindred subjects. The address was a model of lucidity, and at its conclusion Prof. Lorentz received quite an ovation from a crowded audience.

On Tuesday, December 11, Lord Rayleigh gave an interesting account of his investigations on iridescent colours in Nature. He dealt successively with the colours observed in light reflected from potassium chlorate crystals, mother-of-pearl, Labrador felspar, and scarabee. This work was described recently in a series of papers read before the Royal Society.

At the conclusion of the lecture Prof. Volterra presented, on the behalf of the Accademia dei Lincei, two volumes of the collected works of Volta. Other volumes are in preparation.

Wednesday, December 12, was marked by a banquet at which the delegates were royally entertained. The chair was occupied by the Under Secretary of State for Public Instruction. M. Picard (president of the Société Française de Physique) welcomed the foreign delegates, and responses were made by Prof. Volterra, Prof. Lorentz, Lord Rayleigh, Prof. Störmer, and Prof. Knudsen.

The culminating point in the celebrations came on Thursday afternoon, when the chair was taken by the President of the Republic in the large amphitheatre of the Sorbonne. There were also present the Ministers of Commerce, of Public Instruction, and of Public Works. After speeches by M. Picard and M. Brylinski (president of the French Electrotechnical Committee), Prof. Lorentz presented the addresses which had been brought by the delegates. These were numerous, and, in the alphabetical order of the countries from which they came, were from the following societies: L'Académie Royale de Belgique, La Société Scientifique de Bruxelles, L'Académie Royale de Danemark, L'Institut d'Égypte, L'Académie des Sciences de Madrid, Bureau of Standards, Carnegie Institution of Washington, L'Académie des Sciences de Finland, Royal Society, Royal Institution, Physical Society of London, Röntgen Society, Accademia dei Lincei, Accademia di Torino, La Section de Physique du Conseil National de Recherches du Japon, Le Ministère de l'Instruction Publique du Grand Duché de Luxembourg, La Société de Physique de Christiania, L'Académie Royale des Sciences d'Amsterdam, La Société Hollandaise des Sciences de Haarlem, L'Académie de Cracovie, La Société Polonaise de Physique, La Société Suisse de Physique, La Société de Physique et d'Histoire Naturelle de Genève, La Société Zurichoise de Physique et l'École Polytechnique fédérale de l'Université de Zurich, L'Union des Mathématiciens et des Physiciens tchecoslovaques à Prague.

After this part of the ceremony came a speech by M. Bérard (Minister of Public Instruction), followed by remarks by the President of the Republic. The latter with his ministers then withdrew, and we settled down to a discourse by Prof. C. Fabry on the domain of radiations. The programme was interspersed throughout by a selection of music rendered by the celebrated band of the Garde Républicaine.

The magnificent amphitheatre of the Sorbonne, in which these proceedings were held, seats about 3000 people, and gave rise to some reflections, possibly not only on the part of the present writer. Where is such a theatre to be found among our educational institutions in London? Unfortunately, nowhere; and if we had such a theatre, would an audience of, say, 2500 people come on such an occasion, and listen to an address (unillustrated) on the difficulties experienced in exploring the field of radiation, from the longest waves, as used in wireless telegraphy, to the shortest, as shown by X-rays? We doubt it, even if the Prince of Wales were present. The value of science is obviously recognised more fully in Paris than in London.

Lectures by Prof. Störmer on the aurora borealis, on Friday, December 14, and by Prof. Knudsen on the mechanism of evaporation and condensation, on Saturday, brought to a close these very interesting and very successful celebrations.

Virus Diseases of Plants.

AN interesting discussion upon "Virus Diseases of Plants" was held during the meeting of the British Association at Liverpool between the Sections of Botany and Agriculture. These obscure maladies, which are of great economic importance, affect a great variety of cultivated plants and have lately received much attention from plant pathologists. Formerly these diseases were attributed to general physiological degradation, notably in the potato, but since they have been shown to be markedly infectious, they are usually considered to be caused by organisms of ultramicroscopic size, which are disseminated largely by means of insects.

The discussion was opened by Dr. Paul Murphy, who first described the symptoms of these diseases in general and compared them briefly with certain diseases of animals of somewhat similar type. He then dealt specifically with the "leaf-roll" and "mosaic" diseases of potatoes, both of which cause enormous losses in yield. In discussing "leaf-roll" of potatoes, Dr. Murphy maintained that the abnormal accumulation of starch in the leaves, which led to rolling, preceded the degeneration of the phloem, which is also a marked symptom of this disease. In potato "mosaic," characterised first by a mottling of the foliage and later by marked degradation of the whole plant, he stated that this disease sometimes masked other "virus" diseases of the potato such as "stipple-streak" and "crinkle." He had also demonstrated that certain varieties might act as "carriers" of this disease, in which the symptoms remained dormant, although infection could still be spread from these plants. As instancing the rapidity with which degeneration caused by such diseases might occur, Dr. Murphy said that on a farm at Ottawa potatoes had been grown healthily for seventeen years, but that, after this period, marked degeneration set in during the course of a single season, which had affected all potatoes subsequently grown on that farm. He considered, however, that there still remained a certain reduction in yield attributable to non-pathogenic causes when the same healthy stock was grown in different but apparently suitable localities.

Prof. H. M. Quanjer, of Wageningen, Holland, who has made a special study of these diseases in the potato, then gave an account of his own researches on these maladies. In regard to "leaf-roll" he combated the view of Dr. Murphy that the seat of the disturbance lay in the abnormal accumulation of starch in the leaves, maintaining that the primary effect of disease was the necrosis of the phloem consequent upon the entry of the "virus" through insect agency. He pointed out that infection by aphides during May and June first resulted in rolling of the upper leaves during August. Prof. Quanjer claimed that the real seat of these "virus" diseases was the phloem, and suggested therefore that they should be called "phloem diseases" rather than "virus" diseases, although he admitted there was no visible degeneration of the phloem in "mosaic" diseases. In this connexion also it must be conceded that there are other diseases of phloem tissues which do not fall into the category of "virus" diseases. Prof. Quanjer emphasised the rôle played by insects, especially aphides, in the dissemination of these diseases, but pointed out that in some "mosaic" diseases transmission was possible through mechanical abrasion of the leaf hairs.

Dr. W. B. Brierley exhibited lantern slides which showed in a striking manner, by reference to American statistics, the losses caused by these diseases in crop plants. With regard to sugar-cane "mosaic," he stated that varieties resistant to the disease had recently been discovered which would probably prove the salvation of the cane industry in certain districts.

Mr. T. Whitehead classified "virus" plant diseases into four categories, of which the following are examples:

(1) Infectious chlorosis, which is transmissible only by grafting.

(2) Spike disease of the sandal-wood tree, in which there is neither abnormal starch accumulation nor phloem necrosis.

(3) Leaf-roll of potatoes, in which abnormal starch accumulation accompanies phloem necrosis. This disease is transmissible by insects, but not by expressed sap alone.

(4) Potato mosaic, in which there is neither accumulation of starch nor phloem necrosis, although the sugar content may be unusually high.

This disease is transmissible by the sap alone, without insect agency. Mr. Whitehead appealed for more accurate methods in diagnosing this group of diseases, and gave striking evidence for the transmission of potato "leaf-roll" through the soil. He suggested that these diseases could be best controlled by raising resistant varieties and by establishing special beds of potatoes for seed purposes, which could be rogued effectively and lifted early.

Mr. Holmes Smith expressed the view that leaf-roll was by far the most serious of the "virus" diseases of the potato in this country. Unfortunately manurial treatment had no effect upon it, although this was somewhat beneficial in potato mosaic.

Dr. R. N. Salaman pointed out that although this year he had taken the trouble to spray his seedling potatoes, planted in old garden soil, with nicotine at frequent intervals in order to control aphides, infection by mosaic and leaf-roll had been more serious than ever before, although seedlings planted in remote plots in other crops had remained healthy. *Solanum nigrum* appeared to be of no importance as a "carrier" of these diseases. Dr. Salaman expressed the view that "virus" diseases of the potato were probably not congenital, and that susceptibility to leaf-roll was transmitted independently of susceptibility to mosaic disease.

F. T. BROOKS.

Australian Railway Development: a Study in Political Geography.

MR. O. H. T. RISHBETH read a paper on this subject to Section E (Geography) of the British Association at Liverpool. Railway systems typify the humanised as opposed to the purely physical environment, and in so far as they reflect the higher social and political mentality of the people, contribute most useful data for the human geographer. In Europe the system of national states, with their semi-geographical basis, was evolved before the railway era. The railway systems superimposed on a well-defined national background share the intense individualisation of the continent. Europeans brought to Australia this tradition of individualism and exclusiveness.

Mr. Rishbeth maintained that Australia is a clear-cut geographical unity and that its interstate bound-

aries are mathematical and artificial: with one or two exceptions they have no geographical meaning. The early settlements around the island-continent were separated by long stretches of inhospitable coast and still more difficult interior. From these various centres the human settlement developed on old-world lines. This is expressed in the various state railway systems, each planned without reference to those of adjoining states.

The geographical and economic unity of the island was overlooked until a much later date, but the commonwealth feeling or spirit is now making rapid headway and is reflected in the new and newly planned railway lines. These lines are projected to bind together and not to separate the various states. All major Australian railway schemes are essentially commonwealth propositions in that they involve the interests of more than one state. A sketch map was shown to indicate the economic areas, independent of political divisions, which may be regarded as the hinterlands of different stretches of sea coast. On this map it is possible to forecast, with tolerable certainty, the main outlines of the completed Australian railway system. Briefly, this entails an outer ring of which the elements already exist; an inner circle; fragments of a radial system cutting across both circles and joining hinterlands with their appropriate ports; certain overland lines from north to south and east to west. These systems when fully built will unify the continent and overrule the artificiality of the original states.

Structure of Greenland.

WE have recently received, though the work is dated 1920, volume 53 of the "Neue Denkschriften der Schweizerischen Naturforschenden Gesellschaft,"[1] containing an account of the Swiss trans-Greenland Expedition of 1912–13. Between southern Greenland at about lat. 64°, where the country was crossed by Nansen in 1888, and Peary's routes of 1892–95 through 80° N., the interior of Greenland remained unknown for an interval of more than 1000 miles. In order to determine the structure along one line through this gap a Swiss expedition under Prof. de Quervain in 1912 traversed Greenland from the western coast in lat. 69° 46′ opposite Disko to the eastern coast in lat. 66°. The journey on the inland ice was begun on June 20. The summit of the ice-cap was crossed on July 8, and its eastern margin was reached on July 21. The party, with dog-drawn sledges, averaged 22 kilometres a day. Meanwhile the western party under Prof. Mercanton investigated the open country on the western edge of the ice-cap to the east of Disko Island.

The new traverse of Greenland confirms the general accuracy of Nansen's profile, though, as he crossed the country where the ice-cap is narrower but rises to a greater height, his gradients were steeper than those found by the Swiss party. Doubt is thrown as to the distance inland reached by von Nordenskjöld in 1883. The expedition, however, supports his view that cryoconite consists in part of meteoritic material. Nordenskjöld's conclusion has generally been rejected and the material explained as dust blown on to the ice from the nearest rocks. Part of the cryoconite collected by the Swiss expedition is regarded as derived from local diorite, but it contains spherules of magnetite which Prof. Mercanton regards as possibly of extra-terrestrial origin. In this view he supports the conclusions of Wulfing and of Swinne (1919). In the absence, however, of proved nickel, the meteoritic origin of the magnetite may still be regarded as open to doubt.

The western party made careful measurements of the ice movements, and found it to vary from less than a centimetre a day on the ice front to 2½ metres. It is shown that the bare land in west-central Greenland was once covered by the ice-sheet, and Prof. Mercanton supports the view that, with the exception of some of the high southern mountains, the whole of Greenland was once buried under an ice-cap. His account and photographs show the powerful disruptive effect of frost on bare rocks in the neighbourhood of ice. The larger part of the volume is occupied by the meteorological observations and results, including the records of some pilot-balloons.

The last chapter describes the collection of Eskimo skulls, and its author, Dr. Hoessly, rejects the view that the Eskimo reached Greenland from Europe across the Faroes and Iceland; he regards the Eskimo as the most primitive section of the Mongolian race. The volume is well illustrated by four plates of maps and sections, nine plates, and numerous figures in the text.

[1] "Neue Denkschriften der Schweizerischen Naturforschenden Gesellschaft" (Nouveaux Mémoires de la Société Helvétique des Sciences Naturelles) Band 53. Pp. xx+402+54. (Basel, Genf und Lyon: Georg und Co., 1920.)

Building Materials made of Waste Materials.[1]

By Prof. A. P. LAURIE.

WE have in Great Britain large accumulations of blast furnace slag, of cinders, and clinker, and in the neighbourhood of Edinburgh of burnt shale, the residue from the stills of the oil industry. There are three ways in which these materials can be utilised—for the production of bricks, for the production of cement, and as aggregate mixed with Portland cement or plaster of Paris. The general method adopted for the production of bricks is known as the sand lime process. Briefly, this process consists of mixing the aggregate with a certain proportion of lime and water, squeezing it into a brick under a pressure of some two hundred tons to the area of the brick and then steaming under high pressure or in open steaming chambers. Bricks are now being manufactured by this process from sand, blast furnace slag, granulated by being run while hot into water, clinker, town refuse, slate dust, and burnt shale.

Cement is being manufactured by two of the Scottish steel companies from blast furnace slag granulated, mixed with lime, and then raised to a high temperature so as to form a clinker in the same way as ordinary Portland cement was manufactured. This cement, known in Germany as iron cement, can be sold in this condition, or can be finally ground with a mixture of a certain proportion of raw blast furnace slag.

The uses of these materials as an aggregate opens the question of how far it is possible to reduce the content of Portland cement and, at the same time, get sufficient strength for building purposes. The objection to the usual building slab made of cement is that, in order to be able to remove it from the machine as soon as made, the content of water has to be kept low and, consequently, the crushing strength of the finished slab is also low. Two interesting methods of getting over this difficulty are the Crozite method, in which the cement bricks were sliced off from the bottom of a column of cement and aggregate, and the method used by the Triangular Construction Company, in which a heavy compression is put upon the bottom and top of the slab at the

[1] Substance of a lecture delivered at the Royal Academy of Arts, London, on Wednesday, November 21.

moment of completion. It has been possible in the case of the slabs made by the Triangular Construction Company to reduce the amount of cement to one to twelve of aggregate, and the manufacture of cement bricks by the Crozite process is being carried on in a large scale in America.

Many waste products such as sawdust, disintegrated wood, and ordinary cheap aggregates such as clinker can be utilised in slabs made from plaster of Paris. There are large and easily available deposits of gypsum in Great Britain, but the industry has never been developed on the enormous scale found in America, where all kinds of materials required by the builder have been turned out made from plaster of Paris as the cement.

University and Educational Intelligence.

THE *University Bulletin* issued by the Association of University Teachers has hitherto been confined mainly to a record of the activities of the Association, which have been concerned largely with questions of remuneration and other conditions of tenure of university posts. In the November issue an effort is made to widen its circle of readers. Lord Gorell contributes an article dealing with three subjects: (1) expected developments of the functions of the Teachers' Registration Council with the view of the establishment of teaching as one of the unified learned professions; (2) the financial needs of universities; and (3) the projected Imperial Education Bureau. Prof. Arthur Thomson's thoughtful and arresting essay on the essentials of education deserves a wider circulation than the *Bulletin* can hope to give it. Here is a biologist dealing with the ignorance of young Scotland as faithfully as Prof. Burnet in his Romanes lecture dealt with the same subject from the point of view of the humanist. Over the familiar initials M. E. S. appears a plea for large capital grants to universities as recommended by the Royal Commission of 1870 on Scientific Instruction and the Advancement of Science. Prof. Sandbach tells of a committee having been appointed by the A.U.T. to consider and report on the subject of co-operation between libraries, possibly on the lines of the German central information bureau and general card catalogue, for the benefit of research workers in Great Britain and Ireland. There is also a contribution from Melbourne on the perils of inbreeding and localism in universities in the Overseas Dominions.

THE North of Scotland and the Edinburgh and East of Scotland Colleges of Agriculture append to their calendars for 1923–24 lists of appointments gained by their students. They illustrate the Scottish propensity, referred to in Mr. Rudyard Kipling's recent rectorial address, for "raiding the world in all departments of life—and government." The lists include posts in England (53), Canada, the United States, South America, the West Indies, Australia, New Zealand, South, West, East, and Central Africa, the Sudan, Egypt, Cyprus, Hungary, India, Burma, Ceylon, Straits Settlements, Malay States, Java, Sumatra, Borneo, Fiji, and Hawaii: only 60 out of the 280 were in Scotland. The director of studies of the North of Scotland College reports that in 1922–23 a record number of students (27) obtained the degree in agriculture. Both colleges do a large amount of "county extension" work in addition to the instruction and research carried on at their headquarters and at college and experimental stations. The northern college report records 67,096 attendances and 2929 classes and lecture meetings and 11,840 visits to farms and crofts for instruction and advice. A scheme of rural science to be taught in conjunction with school gardening was introduced into several schools and proved efficacious "in creating an interest in school gardening which is lacking at present."

RHODES Scholars in residence at Oxford in 1922–23 numbered 273, namely, 125 from the British Empire and 148 from the United States. Of these, 57 were taking natural science and medicine, 10 economics, and 6 mathematics. Sixty-eight Rhodes scholars were successful in the final honour schools examinations, namely, first class 14 (United States 8, Canada 2, Australia 2, New Zealand 1, South Africa 1); second class 31 (United States 16, others 15); third and fourth classes 23 (United States 11, others 12). The Ph.D. degree was awarded to 7 (all from the United States), the B.Sc. or B.Litt. to 17, and the B.C.L. to 18. Among other academic distinctions obtained by Rhodes scholars may be mentioned the Christopher Welch scholarship in biology and the James Hall Foundation essay prize, both won by Americans, the Francis Gotch memorial prize won by a scholar from New Brunswick, the David Syme research prize (Melbourne) won by a scholar from Victoria, the Bourse des Œuvres françaises à l'étranger (tenable for one year in a university in France) awarded to a New South Wales scholar, two demonstratorships and a tutorial fellowship at Oxford awarded to two Australians and a South African, and a Rockefeller Medical research fellowship, tenable in the United States, to which an Australian scholar was elected. In athletics distinctions were won by 11 scholars from the United States, 10 from Australasia, 6 from Canada, and 4 from South Africa.

A NOTABLE citizen of Bolton, Lancashire, Mr. J. P. Thomasson, made known to the School Board of the Borough in 1876 his intention to allot the sum of 750*l.* annually for a period of ten years, in order to assist scholars from the elementary schools to proceed to higher schools before becoming pupil teachers. His purpose was to secure a body of teachers in elementary schools efficiently educated and properly trained for their duties. The School Board felt that the full benefit to be derived from the scholarships would not be realised if they were restricted to those entering upon the profession of teacher, and Mr. Thomasson consented to enlarge the scope of the scheme so as to encourage pupils from the elementary schools to continue their education at higher schools and to encourage suitable pupils to become teachers. The scheme provided fees, books, railway fares, and a grant towards maintenance. Mr. Thomasson died in 1904, and Mrs. Thomasson intimated her willingness to continue the benefaction for a further period. Meantime the School Board ceased to act and the Town Council became the Education Authority. The scheme was enlarged in its scope, and provision was made for scholarships for boys and girls between 16 and 17 years of age who had been in attendance at secondary schools in Bolton to continue their education in such schools, for leaving scholarships of the annual value of 150*l.* tenable for three years at a university and for a post-graduate scholarship at a foreign university of the annual value of 200*l.* tenable for two years. The scheme has now come to an end. During the 46 years of its existence under varying conditions there have been awarded 122 major exhibitions, 427 minor scholarships, 36 scholarships in respect of continued education at secondary schools, 18 university scholarships, and one post-graduate scholarship. The total sum received from Mr. and Mrs. Thomasson amounts to 26,438*l.*, and the examination expenses, etc., to only 1718*l.* during the whole period, testifying to the fact that the scheme has been most economically administered.

Societies and Academies.

LONDON.

Geological Society, December 5.—Prof. A. C. Seward, president; and, afterwards, Dr. G. T. Prior, in the chair.—The following communications were read: C. W. **Osman**: The geology of the northern border of Dartmoor, between Whiddon Down and Butterdon Down. The Lower Carboniferous rocks may be divided into a Lower Aluminous and a Calcareous Series. The latter commences with grey shales above the Lower Aluminous series, without any physical feature, and contains a volcanic band, generally in a fragmentary condition, mixed with ash, slate, and other fragments, and impregnated with chert; but, at East Underdown, the rock is more solid, and is a quartzless keratophyre. The corresponding mixed igneous rocks of the north-western Dartmoor border, which have been variously described, are altered keratophyres. Above the volcanic band are two limestone-areas: one on the west, near Whiddon Down, and, separated by quartzose rocks, another limestone-area at Drewsteignton. Throughout the length of border considered, the top of the Calcareous Series is formed of grey shales, with hard rock-bands which pass upwards into the Upper Aluminous Series. The granite south of the Carboniferous border-rocks shows three separate intrusions, all from the same magma, but showing sufficient differences to separate them.—D. J. **Farquharson**: The geology of southern Guernsey. With the possible exception of some dykes of doubtful Palæozoic age, the whole of Guernsey consists of pre-Cambrian rocks—gneisses and schists in the south; unfossiliferous shales and grits at Pleinmont; and a series of intrusions in the north, which range from hornblende-gabbro through diorites and tonalites to granites with their accompanying dykes. These dykes not only pierce the last-named suite, but also the gneisses and grits of the south.

PARIS.

Academy of Sciences, November 26.—M. Albin Haller in the chair.—E. L. **Bouvier**: *Ormiscodes gregatus*, a moth the larvæ of which group together to build complex pouches. A description of the building habits of a new species of Ormiscodes found by M. Grisol in the neighbourhood of San Fernando d'Apure, Venezuela. The pouch is built in common, and may contain 10 to 12 cocoons. The name *Ormiscodes gregatus* is proposed for the species.—G. **Friedel**: The black inclusions contained in Cape diamonds. These inclusions have been regarded as graphite, but without clear proof. E. Cohen has shown in a large diamond of 80 carats that the inclusion was a flattened crystal of oligist, and has concluded that many inclusions, if not all, are oligist. The author regards these conclusions as too sweeping, and shows that in the case of a diamond in the University Museum at Strasbourg the inclusion was certainly not oligist, but was very probably graphite.—M. Aimé Cotton was elected a member of the section of general physics in the place of the late J. Violle.—Harald **Bohr**: The approximation of nearly periodic functions by trigonometrical summation.—Pierre **Humbert**: The confluences of Clausen's series.—Léon **Pomey**: Linear integro-differential equations with several variables.—René **Lagrange**: Systems connected with linear differential equations.—Paul **Sonnier**: Thin rectangular plates with edges resting on a fixed surface.—Ernest **Esclangon**: Gliding flight without motive power.—C. E. **Guye**: The motion of the gas in the electromagnetic rotation of the electric discharge. In the case where the action of the positive ions is alone concerned in imparting a movement of rotation to the gas, the observed velocity V can be put in the form

$$V = \frac{\epsilon H}{12\pi\sigma^2 M m}\left[1 + \frac{3N}{M - N}\right],$$

where ϵ is the charge of the ion supposed equal to that of the electron, H the magnetic field producing the rotation, σ and m the radius and mass of the molecule or positive ion, M the total number of molecules, ionised or not, and N the number of positive ions contained in unit volume of the discharge. This expression allows the approximate deduction of N.—R. **Mesny** and P. **David**: Very short waves in wireless telegraphy. With very short wave-lengths it is possible to utilise parabolic mirrors so as to direct the bundle of radiations. The short waves are produced by an arrangement of two symmetrical triodes: waves of wave-length of 1·6 metres can be produced, and telephonic communications have been produced with these at a distance of two kilometres without using mirrors.—Paul **Woog**: The resistance to rupture, lateral compression and equilibrium, of monomolecular layers of various substances in thin films on water.—René **Audubret**: The influence of polarisation on photo-voltaic effects. The mechanism of the phenomenon. The results of the experiments described can be expressed in terms of the Nernst theory by saying that light acts on the electrodes by modifying the solution tension of metals, with an intensity and sense connected with the state of polarisation of the plate.—J. **Pouget** and D. **Chouchak**: The radioactivity of the mineral waters of Algeria.—A. **Lassieur**: An arrangement for electrolysis with graded potentials. The method of Sand and of A. Fischer is modified by replacing the potentiometer measurement by a millivoltmeter and a high resistance.—Camille **Matignon**: A new reaction for the preparation of strontium. Strontia is heated in an iron tube with silicon and the strontium condensed in the cool part of the tube.—M. **Faillebin**: The hydrogenation of certain ketones in the presence of pure or impure platinum black.—A. **Daucet**: The action of xanthydrol on semicarbazide, the substituted semicarbazides, the semicarbazones and benzoylhydrazine. The monoxanthylsemicarbazide is shown to possess the constitution $NH_2.NH.CO.NH.CH(C_6H_7)_2O$, the hydrazine radicle remaining free and capable of combining with aldehydes and ketones in the usual manner.—P. **Gaubert**: The optical properties of graphite and graphitic oxide. The index of refraction of graphite is between 1·93 and 2·07; the crystal is optically negative.—David **Rotman-Roman**: Contributions to the lithology of the Yemen; deep rocks and non-differentiated lode-bearing rocks.—Albert **Michel-Lévy**: Some eruptive rocks from the neighbourhood of Toulon (Var).—Léon **Bertrand** and Léonce **Joleaud**: The relations between the crystalline and sedimentary formations in the western part of Madagascar, between Betsiboka and Tsiribihina.—R. **Dongier**: Magnetic measurements carried out in Dauphiné, Savoie, and Bresse.—Beaulard **de Lenaizan**: The earthquake of November 19, 1923. This shock was recorded on the barograph at Montpellier at 3.40 A.M.—Lucien **Daniel**: New researches on the migration of inulin in grafts of Compositeæ.—A. **Guilliermond**: New observations on the evolution of the chondriome in the embryonic sac of the Liliaceæ.—P. **Lecomte du Noüy**: Meaning of the maximum fall of surface tension of the blood serum.—L. **Mercier** and Raymond **Poisson**: Contribution to the study of the atrophy of the wings and muscles of flight in the Forficulidæ.—Alain **Caillas**: The composition of propolis of bees. Propolis, or bee glue, contains 70 per cent. of resins and 30 per cent. of wax.—Louis **Boutan**: The two zones of external

epithelium of the mantle and their influence on the quality of the pearls in molluscs.—L. **Fage** and R. **Legendre**: The nuptial dances of some species of Nereis.—Boris **Ephrussi**: The action of a high temperature on the mitosis of segmentation of the eggs of the sea urchin.—Nicola Alberto **Barbieri**: Presence of the retina and absence of the optic nerves in anencephalic monsters.—R. **Bazin**: Certain coincidences of malignant neoplasms and their delay in appearance.—E. **Lesné**, L. **de Gennes**, and Ch. O. **Guillaumin**: Study of phosphating in cases of rickets and its variations under the influence of ultraviolet rays.—E. **Wollman** and J. A. **Graves**: Alexic hæmolysis and proteolysis.

CAPE TOWN.

Royal Society of South Africa, October 17.—Dr. A. Ogg, president, in the chair.—K. H. **Barnard**: An example of adaptation in a South African isopod Crustacean. One of the most interesting inhabitants of the empty tubes of the reef-building polychaet worm, *Sabellaria capensis*, is an isopod Crustacean, allied to Eisothistos. This animal has evolved an elongate worm-like shape in strong contrast to the other members of the Isopoda. The "tail-fan" on the other hand is greatly enlarged, and when fully expanded fits the mouth of the worm-tube exactly.—S. H. **Haughton** and A. W. **Rogers**: The volcanic rocks south of Zuurberg. In the divisions of Steytlerville, Uitenhage, and Alexandria, the rocks extend through an area about 100 miles in length from east to west along the northern boundary fault of the Cretaceous beds and are continued southwards round the western end of the Cretaceous area, following it again towards the east on its southern side for 23 miles. The folded belt of rocks belonging to the Cape system and lower part of the Karroo system forms an incomplete "frame" defined by faults on the north, west, and partly on the south, within which there is a sunken area. This area consists of Cretaceous rocks lying unconformably upon an uneven surface of marls, sandstones, sandy tuffs, breccias, and basalts. This latter post-Ecca, pre-Cretaceous formation forms a syncline of post-Uitenhage date, and is unaffected by the intense folding and cleavage of the surrounding region. It can probably be correlated with part of the Stormberg series.—A. V. **Duthie**: Studies in the morphology of *Selaginella pumila*. Part III. The embryo. The megaspores of *Selaginella pumila*, which are shed towards the end of the year, lie dormant on the soil during the summer months and germinate after the early winter rains. Intra-sporal embryos can endure prolonged drying without losing their vitality. The embryo has a prominent foot with large haustorial cells which project into the non-septate storage cavity of the megaspore. The cotyledons do not develop simultaneously, nor are they strictly opposite each other. The first dichotomy of the axis, which takes place at the level of the cotyledons, gives rise to two branches, one of which grows erect; the other develops into a very short horizontal rhizome with branches alternately right and left. The number of cones found on adult plants varied from 1 to 160. The sporophytes are greatly modified by conditions of environment. *S. pumila* possesses a number of characters which are very suggestive of the tree-like Lycopods of the Palæozoic. Its closest relative is the Australian species, *S. Preissiana*.—J. R. **Sutton**: On the genesis of diamond. The various known forms of diamond are attributable to growth only. Crystallisation was not necessarily at a high temperature, and may have been preceded by a condition of plasticity in the carbon. Diamond was deposited from a carbon solvent within cavities, the contour of which determined its final form and habit, in a solid or solidifying matrix.—J. S. v. d. **Lingen**: On the action of some fluorescent antiseptics in the dark. (Preliminary note.)

BRUSSELS.

Royal Academy of Belgium, January 6.—M. Aug. Lameere in the chair.—El. and Em. **Marchal**: The "Homothallism" of some Ascomycetes. In cultures of single spores the following Ascomycetes produce normally fertile perithecia: *Hypocopra fimicola, H. macrospora, Sordaria tetraspora, Philocopra setosa, P. curvicolla, Sporormia intermedia, Choetomium elatum*. Hence these species should be considered as "homothallic."—V. Van **Straelen** and M. E. **Denaeyer**: The fossil eggs of the Upper Cretacean of Rognac in Provence. These fossils have been submitted to a palæontological and mineralogical study. It is not possible to determine with precision the origin of the eggs, but they present more analogies with birds' eggs than with those of reptiles.—P. **Bruylants** and J. **Gevaert**: Contribution to the study of the reaction between organo-magnesium compounds and nitriles. Vinyl-acetic nitrile. Vinyl-acetonitrile with ethylmagnesium bromide gives dipropenyl, two isomers of crotonitrile, and two polymers of the latter.—P. **Bruylants**: The action of organo-magnesium compounds on glutaric nitrile.

February 3.—M. Ch. J. de la Vallée-Poussin in the chair.—Clément **Servais**: A group of three tetrahedra.—C. de la **Vallée-Poussin**: The movement of a heavy homogeneous solid of revolution fixed by a point on its axis.—Th. **de Donder**: The physical interpretation of general relativity.—Lucien **Godeaux**: Cyclic involutions of fourth order belonging to a surface of genus one.

March 3.—M. Ch. J. de la Vallée-Poussin in the chair.—Th. **de Donder**: The physical interpretation of general relativity.—Marcel **Winants**: Intersecants and tangentials.—Victor **Van Straelen**: The systematic position of some decapod Crustacea of the Cretacean epoch.

April 7.—M. Ch. J. de la Vallée-Poussin in the chair.—Th. **de Donder**: Remarks on the Einstein gravific.—P. **Stroobant**: (1) The National Astronomical Committee. An account of the work carried out during the years 1921 and 1922. (2) National Committee of Geodesy and Geophysics. An account of the work done in 1921 and 1922.—Jean **Morelle**: The cytoplasmic constituents in the pancreas and their rôle in secretion.—Laure **Willem**: Researches on the aerial respiration of the Amphibia.

May 8.—M. Léon Fredericq in the chair.—G. **Cesaro**: The equiorientation and similitude of the ellipse of inertia and Steiner's ellipse in the triangle. The Steiner ellipsoids and ellipsoid of inertia of the tetrahedron.—P. **Fourmarier**: The presence of oolitic pebbles in the Tertiary gravels of Cokaifagne (Sart-lez-Spa).—H. **Philippot**: The comparison of time by wireless telegraphy in 1922. A detailed study of the results obtained over one year at the Observatories of Algiers, Edinburgh, Greenwich, and Uccle on the observations of the time signals sent daily from Paris by wireless telegraphy.

June 2.—M. Ch. J. de la Vallée-Poussin in the chair.—P. **Fourmarier**: The supposed glacial phenomena of the Baraque Michel. The author concludes that it is improbable that the plateau of the Baraque Michel has been covered by a glacier.—Laure **Willem**: Aerial respiration in the Amphibia (2).

July 7.—M. Ch. J. de la Vallée-Poussin in the chair.—Jean **Massart**: Researches on the lower organisms. (VIII.) Reflexes in Polyporus.—Cl. **Servais**: The

geometry of the triangle and the tetrahedron.—Francis **Meunier**: The electrolytic overvoltage of hydrogen. A short account of the present knowledge of the phenomena of overvoltage, with an experimental study of the overvoltage of hydrogen on platinum, lead, molybdenum, and tungsten. It has been found that the magnitude of the cathode surface is without influence, the overvoltage increasing as the concentration of the electrolyte diminishes. The fluorine ion, added in small proportions, reduces the overvoltage.—A. **d'Hooghe**: The mechanism of the reduction of oxide of zinc.

August 4.—M. Ch. de la Vallée-Poussin in the chair.—Th. **de Donder**: The fundamental formula of the new gravific.—P. **Fourmarier**: The southern extension of the gap of Theux.—Fréd. **Swarts**: The catalytic hydrogenation of organic compounds containing fluorine. Meta-trifluorcresol treated with hydrogen in the presence of platinum black gives trifluormethyl-cyclo-hexanol, trifluormethyl-cyclohexane, and water. The velocity of the reaction was studied.—Edouard **Herzen**: A simple method of obtaining the stationary orbits of Bohr in the hydrogen spectrum.—L. **Godeaux**: The cyclic involutions of the fourth order belonging to a surface of genus one (2).—G. **Lemaitre**: A property of the Hamiltonians of a multiplier.—Laure **Willem**: Researches on the aerial respiration of the Amphibia (3).

Official Publications Received.

Memoirs of the Department of Agriculture in India. Chemical Series, Vol. 7, No. 3: A Preliminary Note on the Decomposition of Calcium Cyanamide in South Indian Soils. By Dr. Roland V. Norris, B. Viswanath, and C. V. Ramaswami Ayyar. Pp. 55-75. (Calcutta: Thacker, Spink and Co.; London: W. Thacker and Co.) 12 annas; 1s.

Bulletin of the American Museum of Natural History. Vol. 48, Art. 17: New Fossil Mammals from the Pliocene of Sze-Chuan, China. By W. D. Matthew and Walter Granger. Pp. 563-598. Vol. 48, Art. 18: The Problem of the Uintatherium Molars. By Horace Elmer Wood. Pp. 599-604. (New York.)

Department of Agriculture, Madras. Bulletin No. 84: A Soil Survey of the Periyar Tract. By Dr. Roland V. Norris, M. R. Ramaswami Sivan, and S. Kasinatha Ayyar. Pp. 6+10 maps. (Madras: Government Press.) 1.14 rupees.

Meteorology in Mysore for 1922: Being the Results of Observations at Bangalore, Mysore, Hassan, and Chitaldrug. Thirtieth Annual Report, by C. Seshachar. Pp. iii+15. (Bangalore: Government Press.)

Mysore Government: Meteorological Department. Report of Rainfall Registration in Mysore for 1922. By C. Seshachar. Pp. xvii+35. (Bangalore: Government Press.)

Publications of the South African Institute for Medical Research. No. 16: On the Effects of Cold on the Vitality of certain Cysticerci and Echinococci in Meat kept under Commercial Conditions of Freezing in Johannesburg. By Dr. Annie Porter. Pp. 49. (Johannesburg.) 5s.

The Indian Forest Records. Vol. 9, Part 9: Note on the Work of Extraction of Broad Gauge Sleepers from Nepal. By J. V. Collier. Pp. 349-357+15 plates. (Delhi: Government Central Press.) 1.11 rupees.

Geological Survey, Canada. Index to Separate Reports 1906-1910 and Summary Reports 1905-1916. Compiled by F. J. Nicolas. Pp. 305. (Ottawa: F. A. Acland.)

Canada. Department of Mines: Geological Survey. Summary Report, 1922, Part B. Pp. 135B. Summary Report, 1922, Part C. Pp. 91C. (Ottawa: F. A. Acland.)

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Diary of Societies.

SATURDAY, DECEMBER 29.

ROYAL INSTITUTION OF GREAT BRITAIN, at 3.—Sir William Bragg: Concerning the Nature of Things: The Nature of Gases (Juvenile Lectures (2)).

MONDAY, DECEMBER 31.

ROYAL GEOGRAPHICAL SOCIETY (at Æolian Hall), at 3.30.—Mrs. Charles Hose: Boat Journeys in Sarawak (Lecture for Young People).

TUESDAY, JANUARY 1.

CONFERENCE OF EDUCATIONAL ASSOCIATIONS (at University College), at 2.30.—Sir W. Henry Hadow: The Claims of Scholarship (Presidential Address).

ROYAL INSTITUTION OF GREAT BRITAIN, at 3.—Sir William Bragg: Concerning the Nature of Things: The Nature of Liquids (Juvenile Lectures (3)).

MONTESSORI SOCIETY (at University College), at 6.—Miss Barbara Low: The Value of Psycho-Analysis to the Educator.

WEDNESDAY, JANUARY 2.

ROYAL SOCIETY OF ARTS, at 3.—Prof. W. A. Bone: Fire and Explosions (Dr. Mann Juvenile Lectures (1)).

SCHOOL NATURE STUDY UNION (at University College), at 3.—Sir Richard Gregory: The Sun and Stars.

PHYSICAL SOCIETY OF LONDON AND OPTICAL SOCIETY (Annual Exhibition, at the Imperial College of Science and Technology), 3 to 6 and 7 to 10.—At 4.—H. B. Grylls: The Heape and Grylls Rapid Cinema Machine.—At 8.—Sir Richard Paget, Bart.: The Nature and Artificial Reproduction of Human Speech (Vowel Sounds).

ROYAL SOCIETY OF MEDICINE (Surgery Section), at 5.30.—D. Fitzwilliams: A Scientific Method of Removing Foreign Bodies.—A. G. T. Fisher: The Pathology and Treatment of Internal Derangements of the Knee-joint.

INSTITUTION OF ELECTRICAL ENGINEERS (Wireless Section), at 6.—R. H. Barfield: Some Experiments on the Screening of Radio Receiving Apparatus.

ROYAL MICROSCOPICAL SOCIETY (Biological Section), at 7.30.—B. K. Das: The Habits of some Indian Fishes.

THURSDAY, JANUARY 3.

GEOGRAPHICAL ASSOCIATION (at Birkbeck College), at 9.30 A.M.—L. MacD. Robison: Ceylon.—At 11.30 A.M.—Sir Richard Gregory: British Climate in Historic Times (Presidential Address).—At 2.—Joint Conference with the Royal Meteorological Society and the Science Masters' Association. Subjects for Discussion: The Place of Meteorological Observations in the School Course—The Teaching of Meteorology and Climatology in Schools.—At 5.30.—Prof. E. de Martonne: A Study of Transylvania.

ROYAL INSTITUTION OF GREAT BRITAIN, at 3.—Sir William Bragg: Concerning the Nature of Things: The Nature of Crystals—the Diamond (Juvenile Lectures (4)).

PHYSICAL SOCIETY OF LONDON AND OPTICAL SOCIETY (Annual Exhibition at Imperial College of Science and Technology), 3 to 6 and 7 to 10.—At 4.—Sir Richard Paget, Bart.: The Nature and Artificial Reproduction of Human Speech (Vowel Sounds).—At 8.—H. B. Grylls: The Heape and Grylls Rapid Cinema Machine.

INCORPORATED BRITISH ASSOCIATION FOR PHYSICAL TRAINING (at University College), at 5.30.—Major H. J. Selby: The Mental, Moral, and Physical Health of a Nation.

INSTITUTION OF ELECTRICAL ENGINEERS, at 6.—Dr. S. P. Smith: Railway Electrification in Foreign Countries.

FRIDAY, JANUARY 4.

GEOGRAPHICAL ASSOCIATION (at Birkbeck College), at 10.30 A.M.—Conference on The Teaching of Railway Geography.—At 2.30.—Annual Business Meeting.

EUGENICS EDUCATION SOCIETY AND LING ASSOCIATION (at University College), at 3.—Mrs. Hodson: The Teaching of Hygiene and Racial Progress.

ROYAL GEOGRAPHICAL SOCIETY (at Æolian Hall), at 3.30.—Mrs. Julia Henshaw: Camping in the Kootenay, British Columbia (Lecture for Young People).

ROYAL SOCIETY OF ARTS (Indian Section), at 4.30.

ROYAL PHOTOGRAPHIC SOCIETY OF GREAT BRITAIN, at 7.—Pictorial Group Meeting.

JUNIOR INSTITUTION OF ENGINEERS, at 7.30.—L. Manico: Economy of Fuel by Removal of Soot from Boiler Tubes.

PHILOLOGICAL SOCIETY (at University College), at 8.—Prof. S. Boyanus: Russian and English Phonetics.

SATURDAY, JANUARY 5.

ROYAL INSTITUTION OF GREAT BRITAIN, at 3.—Sir William Bragg: Concerning the Nature of Things: The Nature of Crystals—Ice and Snow (Juvenile Lectures (5)).

GILBERT WHITE FELLOWSHIP (at 6 Queen Square, W.C.1), at 3.—Sir David Prain: Gilbert White and Moral History.

Supplement to NATURE

No. 2801 JULY 7, 1923

The Structure of the Atom.[1]

By Prof. N. Bohr.

The General Picture of the Atom.

THE present state of atomic theory is characterised by the fact that we not only believe the existence of atoms to be proved beyond a doubt, but also we even believe that we have an intimate knowledge of the constituents of the individual atoms. I cannot on this occasion give a survey of the scientific developments that have led to this result; I will only recall the discovery of the electron towards the close of the last century, which furnished the direct verification and led to a conclusive formulation of the conception of the atomic nature of electricity which had evolved since the discovery by Faraday of the fundamental laws of electrolysis and Berzelius's electrochemical theory, and had its greatest triumph in the electrolytic dissociation theory of Arrhenius. This discovery of the electron and elucidation of its properties was the result of the work of a large number of investigators, among whom Lenard and J. J. Thomson may be particularly mentioned. The latter especially has made very important contributions to our subject by his ingenious attempts to develop ideas about atomic constitution on the basis of the electron theory. The present state of our knowledge of the elements of atomic structure was reached, however, by the discovery of the atomic nucleus, which we owe to Rutherford, whose work on the radioactive substances discovered towards the close of the last century has much enriched physical and chemical science.

According to our present conceptions, an atom of an element is built up of a nucleus that has a positive electrical charge and is the seat of by far the greatest part of the atomic mass, together with a number of electrons, all having the same negative charge and mass, which move at distances from the nucleus that are very great compared to the dimensions of the nucleus or of the electrons themselves. In this picture we at once see a striking resemblance to a planetary system, such as we have in our own solar system. Just as the simplicity of the laws that govern the motions of the solar system is intimately connected with the circumstance that the dimensions of the moving bodies are small in relation to the orbits, so the corresponding relations in atomic structure provide us with an explanation of an essential feature of natural phenomena in so far as these depend on the properties of the elements. It makes clear at once that these properties can be divided into two sharply distinguished classes.

To the first class belong most of the ordinary physical and chemical properties of substances, such as their state of aggregation, colour, and chemical reactivity. These properties depend on the motion of the electron system and the way in which this motion changes under the influence of different external actions. On account of the large mass of the nucleus relative to that of the electrons and its smallness in comparison to the electron orbits, the electronic motion will depend only to a very small extent on the nuclear mass, and will be determined to a close approximation solely by the total electrical charge of the nucleus. Especially the inner structure of the nucleus and the way in which the charges and masses are distributed among its separate particles will have a vanishingly small influence on the motion of the electron system surrounding the nucleus. On the other hand, the structure of the nucleus will be responsible for the second class of properties that are shown in the radioactivity of substances. In the radioactive processes we meet with an explosion of the nucleus, whereby positive or negative particles, the so-called α- and β-particles, are expelled with very great velocities.

Our conceptions of atomic structure afford us, therefore, an immediate explanation of the complete lack of interdependence between the two classes of properties, which is most strikingly shown in the existence of substances which have to an extraordinarily close approximation the same ordinary physical and chemical properties, even though the atomic weights are not the same, and the radioactive properties are completely different. Such substances, of the existence of which the first evidence was found in the work of Soddy and other investigators on the chemical properties of the radioactive elements, are called isotopes, with reference to the classification of the elements according to ordinary physical and chemical properties. It is

[1] Lecture delivered at Stockholm, December 11, 1922, on the occasion of the receipt of the Nobel prize in physics for the year 1922. English translation by Dr. Frank C. Hoyt.

not necessary for me to state here how it has been shown in recent years that isotopes are found not only among the radioactive elements, but also among ordinary stable elements; in fact, a large number of the latter that were previously supposed simple have been shown by Aston's well-known investigations to consist of a mixture of isotopes with different atomic weights.

The question of the inner structure of the nucleus is still but little understood, although a method of attack is afforded by Rutherford's experiments on the disintegration of atomic nuclei by bombardment with α-particles. Indeed, these experiments may be said to open up a new epoch in natural philosophy in that for the first time the artificial transformation of one element into another has been accomplished. In what follows, however, we shall confine ourselves to a consideration of the ordinary physical and chemical properties of the elements and the attempts which have been made to explain them on the basis of the concepts just outlined.

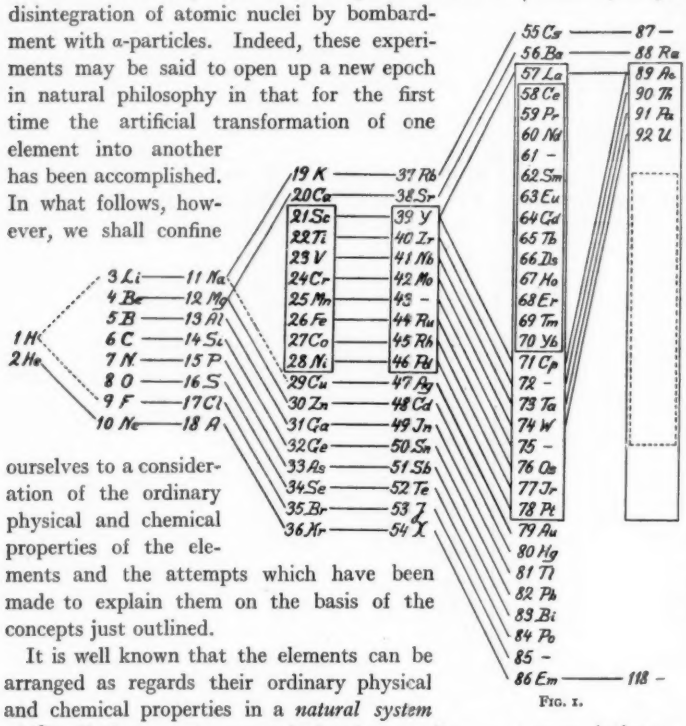

FIG. 1.

It is well known that the elements can be arranged as regards their ordinary physical and chemical properties in a *natural system* which displays most suggestively the peculiar relationships between the different elements. It was recognised for the first time by Mendeléeff and Lothar Meyer that when the elements are arranged in an order which is practically that of their atomic weights, their chemical and physical properties show a pronounced periodicity. A diagrammatic representation of this so-called periodic table is given in Fig. 1, where, however, the elements are not arranged in the ordinary way but in a somewhat modified form of a table first given by Julius Thomsen, who has also made important contributions to science in this domain. In the figure the elements are denoted by their usual chemical symbols, and the different vertical columns indicate the so-called periods. The elements in successive columns which possess homologous chemical and physical properties are connected with lines. The meaning of the square brackets around certain series of elements in the later periods, the properties of which exhibit typical deviations from the simple periodicity in the first periods, will be discussed later.

In the development of the theory of atomic structure the characteristic features of the natural system have found a surprisingly simple interpretation. Thus we are led to assume that the ordinal number of an element in the periodic table, the so-called atomic number, is just equal to the number of electrons which move about the nucleus in the neutral atom. In an imperfect form, this law was first stated by Van den Broek; it was, however, foreshadowed by J. J. Thomson's investigations of the number of electrons in the atom, as well as by Rutherford's measurements of the charge on the atomic nucleus. As we shall see, convincing support for this law has since been obtained in various ways, especially by Moseley's famous investigations of the X-ray spectra of the elements. We may perhaps also point out, how the simple connexion between atomic number and nuclear charge offers an explanation of the laws governing the changes in chemical properties of the elements after expulsion of α- or β-particles, which found a simple formulation in the so-called radioactive displacement law.

Atomic Stability and Electrodynamic Theory.

As soon as we try to trace a more intimate connexion between the properties of the elements and atomic structure, we encounter profound difficulties, in that essential differences between an atom and a planetary system show themselves here in spite of the analogy we have mentioned.

The motions of the bodies in a planetary system, even though they obey the general law of gravitation, will not be completely determined by this law alone, but will depend largely on the previous history of the system. Thus the length of the year is not determined by the masses of the sun and the earth alone, but depends also on the conditions that existed during the formation of the solar system, of which we have very little knowledge. Should a sufficiently large foreign body some day traverse our solar system, we might among other effects expect that from that

day the length of the year would be different from its present value.

It is quite otherwise in the case of atoms. The definite and unchangeable properties of the elements demand that the state of an atom cannot undergo permanent changes due to external actions. As soon as the atom is left to itself again, its constituent particles must arrange their motions in a manner which is completely determined by the electric charges and masses of the particles. We have the most convincing evidence of this in spectra, that is, in the properties of the radiation emitted from substances in certain circumstances, which can be studied with such great precision. It is well known that the wave-lengths of the spectral lines of a substance, which can in many cases be measured with an accuracy of more than one part in a million, are, in the same external circumstances, always exactly the same within the limit of error of the measurements, and quite independent of the previous treatment of this substance. It is just to this circumstance that we owe the great importance of spectral analysis, which has been such an invaluable aid to the chemist in the search for new elements, and has also shown us that even on the most distant bodies of the universe there occur elements with exactly the same properties as on the earth.

On the basis of our picture of the constitution of the atom it is thus impossible, so long as we restrict ourselves to the ordinary mechanical laws, to account for the characteristic atomic stability which is required for an explanation of the properties of the elements.

The situation is by no means improved if we also take into consideration the well-known electrodynamic laws which Maxwell succeeded in formulating on the basis of the great discoveries of Oersted and Faraday in the first half of the last century. Maxwell's theory has not only shown itself able to account for the already known electric and magnetic phenomena in all their details, but has also celebrated its greatest triumph in the prediction of the electromagnetic waves which were discovered by Hertz, and are now so extensively used in wireless telegraphy.

For a time it seemed as though this theory would also be able to furnish a basis for an explanation of the details of the properties of the elements, after it had been developed, chiefly by Lorentz and Larmor, into a form consistent with the atomistic conception of electricity. I need only remind you of the great interest that was aroused when Lorentz, shortly after the discovery by Zeeman of the characteristic changes that spectral lines undergo when the emitting substance is brought into a magnetic field, could give a natural and simple explanation of the main features of the phenomenon. Lorentz assumed that the radiation which we observe in a spectral line is sent out from an electron executing simple harmonic vibrations about a position of equilibrium in precisely the same manner as the electromagnetic waves in radio-telegraphy are sent out by the electric oscillations in the antennæ. He also pointed out how the alteration observed by Zeeman in the spectral lines corresponded exactly to the alteration in the motion of the vibrating electron which one would expect to be produced by the magnetic field.

It was, however, impossible on this basis to give a closer explanation of the spectra of the elements, or even of the general type of the laws holding with great exactness for the wave-lengths of lines in these spectra, which had been established by Balmer, Rydberg, and Ritz. After we obtained details as to the constitution of the atom, this difficulty became still more manifest; in fact, so long as we confine ourselves to the classical electrodynamic theory we cannot even understand why we obtain spectra consisting of sharp lines at all. This theory can even be said to be incompatible with the assumption of the existence of atoms possessing the structure we have described, in that the motions of the electrons would claim a continuous radiation of energy from the atom, which would cease only when the electrons had fallen into the nucleus.

The Origin of the Quantum Theory.

It has, however, been possible to avoid the various difficulties of the electrodynamic theory by introducing concepts borrowed from the so-called quantum theory, which marks a complete departure from the ideas that have hitherto been used for the explanation of natural phenomena. This theory was originated by Planck, in the year 1900, in his investigations on the law of heat radiation, which, because of its independence of the individual properties of substances, lent itself peculiarly well to a test of the applicability of the laws of classical physics to atomic processes.

Planck considered the equilibrium of radiation between a number of systems with the same properties as those on which Lorentz had based his theory of the Zeeman effect, but he could now show not only that classical physics could not account for the phenomena of heat radiation, but also that a complete agreement with the experimental law could be obtained if—in pronounced contradiction to classical theory—it were assumed that the energy of the vibrating electrons could not change continuously, but only in such a way that the energy of the system always remained equal to a whole number of so-called energy-quanta. The magnitude of this quantum was found

to be proportional to the frequency of oscillation of the particle, which, in accordance with classical concepts, was supposed to be also the frequency of the emitted radiation. The proportionality factor had to be regarded as a new universal constant, since termed Planck's constant, similar to the velocity of light and the charge and mass of the electron.

Planck's surprising result stood at first completely isolated in natural science, but with Einstein's significant contributions to this subject a few years after, a great variety of applications was found. In the first place, Einstein pointed out that the condition limiting the amount of vibrational energy of the particles could be tested by investigation of the specific heat of crystalline bodies, since in the case of these we have to do with similar vibrations, not of a single electron, but of whole atoms about positions of equilibrium in the crystal lattice. Einstein was able to show that the experiment confirmed Planck's theory, and through the work of later investigators this agreement has proved quite complete. Furthermore, Einstein emphasised another consequence of Planck's results, namely, that radiant energy could only be emitted or absorbed by the oscillating particle in so-called "quanta of radiation," the magnitude of each of which was equal to Planck's constant multiplied by the frequency.

In his attempts to give an interpretation of this result, Einstein was led to the formulation of the so-called "hypothesis of light-quanta," according to which the radiant energy, in contradiction to Maxwell's electromagnetic theory of light, would not be propagated as electromagnetic waves, but rather as concrete light atoms, each with an energy equal to that of a quantum of radiation. This concept led Einstein to his well-known theory of the photo-electric effect. This phenomenon, which had been entirely unexplainable on the classical theory, was thereby placed in a quite different light, and the predictions of Einstein's theory have received such exact experimental confirmation in recent years, that perhaps the most exact determination of Planck's constant is afforded by measurements on the photo-electric effect. In spite of its heuristic value, however, the hypothesis of light-quanta, which is quite irreconcilable with so-called interference phenomena, is not able to throw light on the nature of radiation. I need only recall that these interference phenomena constitute our only means of investigating the properties of radiation and therefore of assigning any closer meaning to the frequency which in Einstein's theory fixes the magnitude of the light-quantum.

In the following years many efforts were made to apply the concepts of the quantum theory to the question of atomic structure, and the principal emphasis was sometimes placed on one and sometimes on the other of the consequences deduced by Einstein from Planck's result. As the best known of the attempts in this direction, from which, however, no definite results were obtained, I may mention the work of Stark, Sommerfeld, Hasenöhrl, Haas, and Nicholson.

From this period also dates an investigation by Bjerrum on infra-red absorption bands, which, although it had no direct bearing on atomic structure, proved significant for the development of the quantum theory. He directed attention to the fact that the rotation of the molecules in a gas might be investigated by means of the changes in certain absorption lines with temperature. At the same time he emphasised the fact that the effect should not consist of a continuous widening of the lines such as might be expected from classical theory, which imposed no restrictions on the molecular rotations, but in accordance with the quantum theory he predicted that the lines should be split up into a number of components, corresponding to a sequence of distinct possibilities of rotation. This prediction was confirmed a few years later by Eva von Bahr, and the phenomenon may still be regarded as one of the most striking evidences of the reality of the quantum theory, even though from our present point of view the original explanation has undergone a modification in essential details.

The Quantum Theory of Atomic Constitution.

The question of further development of the quantum theory was in the meantime placed in a new light by Rutherford's discovery of the atomic nucleus (1911). As we have already seen, this discovery made it quite clear that by classical conceptions alone it was quite impossible to understand the most essential properties of atoms. One was therefore led to seek for a formulation of the principles of the quantum theory that could immediately account for the stability in atomic structure and the properties of the radiation sent out from atoms, of which the observed properties of substances bear witness. Such a formulation was proposed (1913) by the present lecturer in the form of two postulates, which may be stated as follows:

1. Among the conceivably possible states of motion in an atomic system there exist a number of so-called *stationary states* which, in spite of the fact that the motion of the particles in these states obeys the laws of classical mechanics to a considerable extent, possess a peculiar, mechanically unexplainable stability, of such a sort that every permanent change in the motion of the system must consist in a complete transition from one stationary state to another.

2. While in contradiction to the classical electromagnetic theory no radiation takes place from the atom in the stationary states themselves, a process of transition between two stationary states can be accompanied by the emission of electromagnetic radiation, which will have the same properties as that which would be sent out according to the classical theory from an electrified particle executing an harmonic vibration with constant frequency. This frequency ν has, however, no simple relation to the motion of the particles of the atom, but is given by the relation

$$h\nu = E' - E'',$$

where h is Planck's constant, and E' and E'' are the values of the energy of the atom in the two stationary states that form the initial and final state of the radiation process. Conversely, irradiation of the atom with electromagnetic waves of this frequency can lead to an absorption process, whereby the atom is transformed back from the latter stationary state to the former.

While the first postulate has in view the general stability of the atom, the second postulate has chiefly in view the existence of spectra with sharp lines. Furthermore, the quantum theory condition entering in the last postulate affords a starting point for the interpretation of the laws of series spectra. The most general of these laws, the combination principle enunciated by Ritz, states that the frequency ν for each of the lines in the spectrum of an element can be represented by the formula

$$\nu = T'' - T',$$

where T'' and T' are two so-called "spectral terms" belonging to a manifold of such terms characteristic of the substance in question.

According to our postulates, this law finds an immediate interpretation in the assumption that the spectrum is emitted by transitions between a number of stationary states in which the numerical value of the energy of the atom is equal to the value of the spectral term multiplied by Planck's constant. This explanation of the combination principle is seen to differ fundamentally from the usual ideas of electrodynamics, as soon as we consider that there is no simple relation between the motion of the atom and the radiation sent out. The departure of our considerations from the ordinary ideas of natural philosophy becomes particularly evident, however, when we observe that the occurrence of two spectral lines, corresponding to combinations of the same spectral term with two other different terms, implies that the nature of the radiation sent out from the atom is not determined only by the motion of the atom at the beginning of the radiation process, but also depends on the state to which the atom is transferred by the process.

At first glance one might, therefore, think that it would scarcely be possible to bring our formal explanation of the combination principle into direct relation with our views regarding the constitution of the atom, which, indeed, are based on experimental evidence interpreted on classical mechanics and electrodynamics. A closer investigation, however, should make it clear that a definite relation may be obtained between the spectra of the elements and the structure of their atoms on the basis of the postulates.

The Hydrogen Spectrum.

The simplest spectrum we know is that of hydrogen. The frequencies of its lines may be represented with great accuracy by means of Balmer's formula:

$$\nu = K\left(\frac{1}{n''^2} - \frac{1}{n'^2}\right),$$

where K is a constant and n' and n'' are two integers. In the spectrum we accordingly meet a single series of spectral terms of the form K/n^2, which decrease regularly with increasing term number n. In accordance with the postulates, we shall therefore assume that each of the hydrogen lines is emitted by a transition between two states belonging to a series of stationary states of the hydrogen atom in which the numerical value of the atom's energy is equal to hK/n^2.

Following our picture of atomic structure, a hydrogen atom consists of a positive nucleus and an electron which—so far as ordinary mechanical conceptions are applicable—will with great approximation describe a periodic elliptical orbit with the nucleus at one focus. The major axis of the orbit is inversely proportional to the work necessary completely to remove the electron from the nucleus, and, in accordance with the above, this work in the stationary states is just equal to hK/n^2. We thus arrive at a manifold of stationary states for which the major axis of the electron orbit takes on a series of discrete values proportional to the squares of the whole numbers. The accompanying Fig. 2 shows these relations diagrammatically. For the sake of simplicity the electron orbits in the stationary states are represented by circles, although in reality the theory places no restriction on the eccentricity of the orbit, but only determines the length of the major axis. The arrows represent the transition processes that correspond to the red and green hydrogen lines, $H\alpha$ and $H\beta$, the frequency of which is given by means of the Balmer formula when we put $n''=2$ and $n'=3$ and 4 respectively. The transition processes are also represented which correspond to the first three lines of the series

of ultra-violet lines found by Lyman in 1914, of which the frequencies are given by the formula when n is put equal to 1, as well as to the first line of the infra-red series discovered some years previously by Paschen, which are given by the formula if n'' is put equal to 3.

This explanation of the origin of the hydrogen spectrum leads us quite naturally to interpret this spectrum as the manifestation of a process whereby the electron is bound to the nucleus. While the largest spectral term with term number 1 corresponds to the final stage in the binding process, the small spectral terms that have larger values of the term number correspond to stationary states which represent the initial states of the binding process, where the

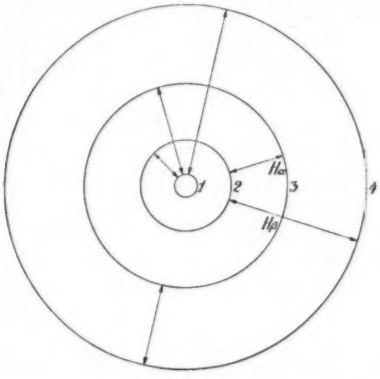

FIG. 2.

electron orbits still have large dimensions, and where the work required to remove an electron from the nucleus is still small. The final stage in the binding process we may designate as the normal state of the atom, and it is distinguished from the other stationary states by the property that, in accordance with the postulates, the state of the atom can only be changed by the addition of energy whereby the electron is transferred to an orbit of larger dimensions corresponding to an earlier stage of the binding process.

The size of the electron orbit in the normal state calculated on the basis of the above interpretation of the spectrum agrees roughly with the value for the dimensions of the atoms of the elements that have been calculated by the kinetic theory of matter from the properties of gases. Since, however, as an immediate consequence of the stability of the stationary states that is claimed by the postulates, we must suppose that the interaction between two atoms during a collision cannot be completely described with the aid of the laws of classical mechanics, such a comparison as this cannot be carried further on the basis of such considerations as those just outlined.

A more intimate connexion between the spectra and the atomic model has been revealed, however, by an investigation of the motion in those stationary states where the term number is large, and where the dimensions of the electron orbit and the frequency of revolution in it vary relatively little when we go from one stationary state to the next following. It was possible to show that the frequency of the radiation sent out during the transition between two stationary states, the difference of the term numbers of which is small in comparison to these numbers themselves, tended to coincide in frequency with one of the harmonic components into which the electron motion could be resolved, and accordingly also with the frequency of one of the wave trains in the radiation which would be emitted according to the laws of ordinary electrodynamics.

The condition that such a coincidence should occur in this region where the stationary states differ but little from one another proves to be that the constant in the Balmer formula can be expressed by means of the relation

$$K = \frac{2\pi^2 e^4 m}{h^3},$$

where e and m are respectively the charge and mass of the electron, while h is Planck's constant. This relation has been shown to hold to within the considerable accuracy with which, especially through the beautiful investigations of Millikan, the quantities e, m, and h are known.

This result shows that there exists a connexion between the hydrogen spectrum and the model for the hydrogen atom which, on the whole, is as close as we might hope considering the departure of the postulates from the classical mechanical and electrodynamic laws. At the same time, it affords some indication of how we may perceive in the quantum theory, in spite of the fundamental character of this departure, a natural generalisation of the fundamental concepts of the classical electrodynamic theory. To this most important question we shall return later, but first we will discuss how the interpretation of the hydrogen spectrum on the basis of the postulates has proved suitable in several ways, for elucidating the relation between the properties of the different elements.

Relationships between the Elements.

The discussion above can be applied immediately to the process whereby an electron is bound to a nucleus with any given charge. The calculations show that, in the stationary state corresponding to a given value of the number n, the size of the orbit will be inversely proportional to the nuclear charge, while the work necessary to remove an electron will be directly proportional to the square of the nuclear charge. The spectrum that is emitted during the binding of an electron by a nucleus with charge N

times that of the hydrogen nucleus can therefore be represented by the formula:

$$\nu = N^2 K\left(\frac{1}{n''^2} - \frac{1}{n'^2}\right).$$

If in this formula we put $N = 2$, we get a spectrum which contains a set of lines in the visible region which was observed many years ago in the spectrum of certain stars. Rydberg assigned these lines to hydrogen because of the close analogy with the series of lines represented by the Balmer formula. It was never possible to produce these lines in pure hydrogen, but just before the theory for the hydrogen spectrum was put forward, Fowler succeeded in observing the series in question by sending a strong discharge through a mixture of hydrogen and helium. This investigator also assumed that the lines were hydrogen lines, because there existed no experimental evidence from which it might be inferred that two different substances could show properties resembling each other so much as the spectrum in question and that of hydrogen. After the theory was put forward, it became clear, however, that the observed lines must belong to a spectrum of helium, but that they were not like the ordinary helium spectrum emitted from the neutral atom. They came from an ionised helium atom which consists of a single electron moving about a nucleus with double charge. In this way there was brought to light a new feature of the relationship between the elements, which corresponds exactly with our present ideas of atomic structure, according to which the physical and chemical properties of an element depend in the first instance only on the electric charge of the atomic nucleus.

Soon after this question was settled the existence of a similar general relationship between the properties of the elements was brought to light by Moseley's well-known investigations on the characteristic X-ray spectra of the elements, which was made possible by Laue's discovery of the interference of X-rays in crystals and the investigations of W. H. and W. L. Bragg on this subject. It appeared, in fact, that the X-ray spectra of the different elements possessed a much simpler structure and a much greater mutual resemblance than their optical spectra. In particular, it appeared that the spectra changed from element to element in a manner that corresponded closely to the formula given above for the spectrum emitted during the binding of an electron to a nucleus, provided N was put equal to the atomic number of the element concerned. This formula was even capable of expressing, with an approximation that could not be without significance, the frequencies of the strongest X-ray lines, if small whole numbers were substituted for n' and n''.

This discovery was of great importance in several respects. In the first place, the relationship between the X-ray spectra of different elements proved so simple that it became possible to fix without ambiguity the atomic number for all known substances, and in this way to predict with certainty the atomic number of all such hitherto unknown elements for which there is a place in the natural system. Fig. 3 shows how the square root of the frequency for two characteristic X-ray lines depends on the atomic number. These lines belong to the group of so-called K-lines, which are the most penetrating of the characteristic rays. With very close approximation the points lie on straight lines, and the fact that they do so is conditioned not only by our taking account of known elements, but also by our leaving an open place between molybdenum (42) and ruthenium (44), just as in Mendeléeff's original scheme of the natural system of the elements.

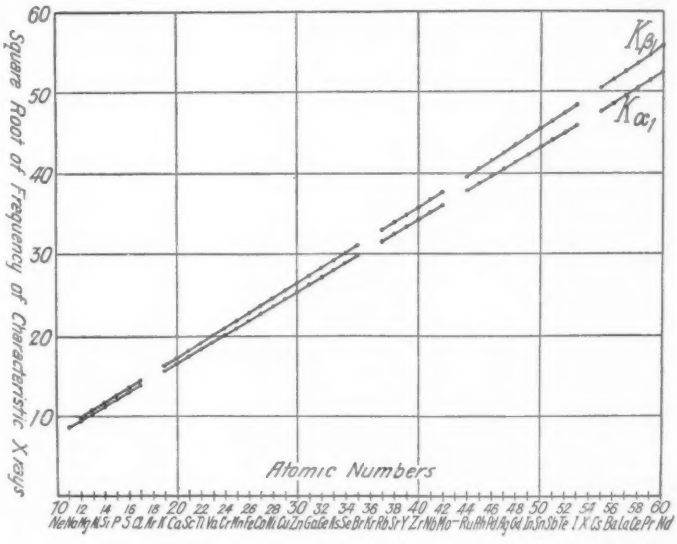
Square Root of Frequency of Characteristic X rays
60
50
40
30
20
10
K_{β_1}
K_{α_1}
Atomic Numbers
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60
Ne Na Mg Al Si P S Cl Ar K Ca Sc Ti Va Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr Rb Sr Y Zr Nb Mo — Ru Rh Pd Ag Cd In Sn Sb Te I X Cs Ba La Ce Pr Nd

FIG. 3.

Further, the laws of X-ray spectra provide a confirmation of the general theoretical conceptions, both with regard to the constitution of the atom and the ideas that have served as a basis for the interpretation

of spectra. Thus the similarity between X-ray spectra and the spectra emitted during the binding of a single electron to a nucleus may be simply interpreted from the fact that the transitions between stationary states with which we are concerned in X-ray spectra are accompanied by changes in the motion of an electron in the inner part of the atom, where the influence of the attraction of the nucleus is very great compared with the repulsive forces of the other electrons.

The relations between other properties of the elements are of a much more complicated character, which originates in the fact that we have to do with processes concerning the motion of the electrons in the outer part of the atom, where the forces that the electrons exert on one another are of the same order of magnitude as the attraction towards the nucleus, and where, therefore, the details of the interaction of the electrons play an important part. A characteristic example of such a case is afforded by the spatial extension of the atoms of the elements. Lothar Meyer himself directed attention to the characteristic periodic change exhibited by the ratio of the atomic weight to the density, the so-called atomic volume, of the elements in the natural system. An idea of these facts is given by Fig. 4, in which the atomic volume is represented as a function of the atomic number. A greater difference between this and the previous figure could scarcely be imagined. While the X-ray spectra vary uniformly with the atomic number, the atomic volumes show a characteristic periodic change which corresponds exactly to the change in the chemical properties of the elements.

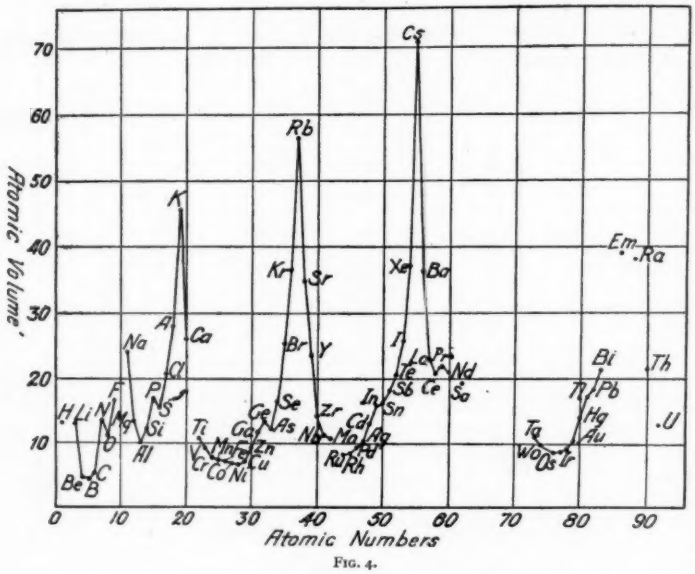

FIG. 4.

Ordinary optical spectra behave in an analogous way. In spite of the dissimilarity between these spectra, Rydberg succeeded in tracing a certain general relationship between the hydrogen spectrum and other spectra. Even though the spectral lines of the elements with higher atomic number appear as combinations of a more complicated manifold of spectral terms which is not so simply co-ordinated with a series of whole numbers, still the spectral terms can be arranged in series each of which shows a strong similarity to the series of terms in the hydrogen spectrum. This similarity appears in the fact that the terms in each series can, as Rydberg pointed out, be very accurately represented by the formula $K/(n+\alpha)^2$, where K is the same constant that occurs in the hydrogen spectrum, often called the Rydberg constant, while n is the term number, and α a constant which is different for the different series.

This relationship with the hydrogen spectrum leads us immediately to regard these spectra as the *last step of a process whereby the neutral atom is built up by the capture and binding of electrons to the nucleus*, one by one. In fact, it is clear that the last electron captured, so long as it is in that stage of the binding process in which its orbit is still large compared to the orbits of the previously bound electrons, will be subjected to a force from the nucleus and these electrons, that differs but little from the force with which the electron in the hydrogen atom is attracted towards the nucleus while it is moving in an orbit of corresponding dimensions.

The spectra so far considered, for which Rydberg's laws hold, are excited by means of electric discharge under ordinary conditions and are often called arc spectra. The elements emit also another type of spectrum, the so-called spark spectra, when they are subjected to an extremely powerful discharge. Hitherto it was impossible to disentangle the spark spectra in the same way as the arc spectra. Shortly after the above view on the origin of arc spectra was brought forward, however, Fowler found (1914) that an empirical expression for the spark spectrum lines could be established which corresponds exactly to Rydberg's laws with the single difference that the constant K is replaced by a constant four times as large. Since, as we have seen, the constant that appears in the spectrum sent out during the binding

of an electron to a helium nucleus is exactly equal to 4 K, it becomes evident that spark spectra are due to the ionised atom, and that their emission corresponds to *the last step but one in the formation of the neutral atom* by the successive capture and binding of electrons.

Absorption and Excitation of Spectral Lines.

The interpretation of the origin of the spectra was also able to explain the characteristic laws that govern absorption spectra. As Kirchhoff and Bunsen had already shown, there is a close relation between the selective absorption of substances for radiation and their emission spectra, and it is on this that the application of spectrum analysis to the heavenly bodies essentially rests. Yet on the basis of the classical electromagnetic theory, it is impossible to understand why substances in the form of vapour show absorption for certain lines in their emission spectrum and not for others.

On the basis of the postulates given above we are, however, led to assume that the absorption of radiation corresponding to a spectral line emitted by a transition from one stationary state of the atom to a state of less energy is brought about by the return of the atom from the last-named state to the first. We thus understand immediately that in ordinary circumstances a gas or vapour can only show selective absorption for spectral lines that are produced by a transition from a state corresponding to an earlier stage in the binding process to the normal state. Only at higher temperatures or under the influence of electric discharges whereby an appreciable number of atoms are being constantly disrupted from the normal state, can we expect absorption for other lines in the emission spectrum in agreement with the experiments.

A most direct confirmation for the general interpretation of spectra on the basis of the postulates has also been obtained by investigations on the excitation of spectral lines and ionisation of atoms by means of impact of free electrons with given velocities. A decided advance in this direction was marked by the well-known investigations of Franck and Hertz (1914). It appeared from their results that by means of electron impacts it was impossible to impart to an atom an arbitrary amount of energy, but only such amounts as corresponded to a transfer of the atom from its normal state to another stationary state of the existence of which the spectra assure us, and the energy of which can be inferred from the magnitude of the spectral term.

Further, striking evidence was afforded of the independence that, according to the postulates, must be attributed to the processes which give rise to the emission of the different spectral lines of an element. Thus it could be shown directly that atoms that were transferred in this manner to a stationary state of greater energy were able to return to the normal state with emission of radiation corresponding to a single spectral line.

Continued investigations on electron impacts, in which a large number of physicists have shared, have also produced a detailed confirmation of the theory concerning the excitation of series spectra. Especially it has been possible to show that for the *ionisation* of an atom by electron impact an amount of energy is necessary that is exactly equal to the work required, according to the theory, to remove the last electron captured from the atom. This work can be determined directly as the product of Planck's constant and the spectral term corresponding to the normal state, which, as mentioned above, is equal to the limiting value of the frequencies of the spectral series connected with selective absorption.

The Quantum Theory of Multiply-Periodic Systems.

While it was thus possible by means of the fundamental postulates of the quantum theory to account directly for certain general features of the properties of the elements, a closer development of the ideas of the quantum theory was necessary in order to account for these properties in further detail. In the course of the last few years a more general theoretical basis has been attained through the development of formal methods that permit the fixation of the stationary states for electron motions of a more general type than those we have hitherto considered. For a simply periodic motion such as we meet in the pure harmonic oscillator, and at least to a first approximation, in the motion of an electron about a positive nucleus, the manifold of stationary states can be simply co-ordinated to a series of whole numbers. For motions of the more general class mentioned above, the so-called *multiply-periodic* motions, however, the stationary states compose a more complex manifold, in which, according to these formal methods, each state is characterised by several whole numbers, the so-called "quantum numbers."

In the development of the theory a large number of physicists have taken part, and the introduction of several quantum numbers can be traced back to the work of Planck himself. But the definite step which gave the impetus to further work was made by Sommerfeld (1915) in his explanation of the fine structure shown by the hydrogen lines when the spectrum is observed with a spectroscope of high resolving power. The occurrence of this fine structure must be ascribed to the circumstance that we have to deal, even in hydrogen, with a motion which is not exactly simply periodic. In fact, as a consequence of the change in the electron's mass with velocity that is claimed by the theory of relativity, the electron orbit will undergo a very slow precession in the orbital plane. The motion will therefore be doubly periodic, and besides a number characterising the term in the Balmer formula, which we shall call the *principal quantum number* because it determines in the main the energy of the atom, the fixation of the stationary

states demands another quantum number which we shall call the *subordinate quantum number*.

A survey of the motion in the stationary states thus fixed is given in the diagram (Fig. 5), which reproduces the relative size and form of the electron orbits. Each orbit is designated by a symbol n_k, where n is the principal quantum number and k the subordinate quantum number. All orbits with the same principal quantum number have, to a first approximation, the same major axis, while orbits with the same value of k have the same parameter, *i.e.* the same value for the shortest chord through the focus. Since the energy values for different states with the same value of n but different values of k differ a little from each other, we get for each hydrogen line corresponding to definite values of n' and n'' in the Balmer formula a number of different transition processes, for which the frequencies of the emitted radiation as calculated by the second postulate are

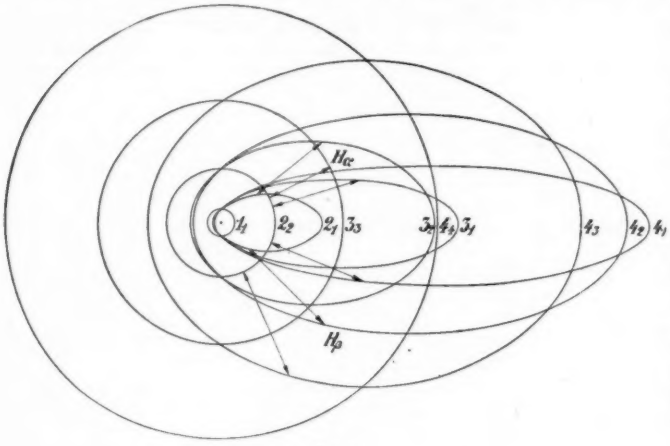

FIG. 5.

not exactly the same. As Sommerfeld was able to show, the components this gives for each hydrogen line agree with the observations on the fine structure of hydrogen lines to within the limits of experimental error. In the figure the arrows designate the processes that give rise to the components of the red and green lines in the hydrogen spectrum, the frequencies of which are obtained by putting $n''=2$ and $n'=3$ or 4 respectively in the Balmer formula.

In considering the figure it must not be forgotten that the description of the orbit is there incomplete, in so much as with the scale used the slow precession does not show at all. In fact, this precession is so slow that even for the orbits that rotate most rapidly the electron performs about 40,000 revolutions before the perihelion has gone round once. Nevertheless, it is this precession alone that is responsible for the multiplicity of the stationary states characterised by the subordinate quantum number. If, for example, the hydrogen atom is subjected to a small disturbing force which perturbs the regular precession, the electron orbit in the stationary states will have a form altogether different from that given in the figure. This implies that the fine structure will change its character completely, but the hydrogen spectrum will continue to consist of lines that are given to a close approximation by the Balmer formula, due to the fact that the approximately periodic character of the motion will be retained. Only when the disturbing forces become so large that even during a single revolution of the electron the orbit is appreciably disturbed, will the spectrum undergo essential changes. The statement often advanced that the introduction of two quantum numbers should be a necessary condition for the explanation of the Balmer formula must therefore be considered as a misconception of the theory.

Sommerfeld's theory has proved itself able to account not only for the fine structure of the hydrogen lines, but also for that of the lines in the helium spark spectrum. Owing to the greater velocity of the electron, the intervals between the components into which a line is split up are here much greater and can be measured with much greater accuracy. The theory was also able to account for certain features in the fine structure of X-ray spectra, where we meet frequency differences that may even reach a value more than a million times as great as those of the frequency differences for the components of the hydrogen lines.

Shortly after this result had been attained, Schwarzschild and Epstein (1916) simultaneously succeeded, by means of similar considerations, in accounting for the characteristic changes that the hydrogen lines undergo in an electric field, which had been discovered by Stark in the year 1914. Next, an explanation of the essential features of the Zeeman effect for the hydrogen lines was worked out at the same time by Sommerfeld and Debye (1917). In this instance the application of the Postulates involved the consequence that only certain orientations of the atom relative to the magnetic field were allowable, and this characteristic consequence of the quantum theory has quite recently received a most direct confirmation in the beautiful researches of Stern and Gerlach on the deflexion of swiftly-moving silver atoms in a non-homogenous magnetic field.

The Correspondence Principle.

While this development of the theory of spectra was based on the working out of formal methods for the fixation of stationary states, the present lecturer succeeded shortly afterwards in throwing light on the theory from a new view-point, by pursuing further the characteristic connexion between the quantum theory and classical electrodynamics already traced out in the hydrogen spectrum. In connexion with the important work of Ehrenfest and Einstein these efforts led to the formulation of the so-called *correspondence principle*, according to which the occurrence of transitions between the stationary states accompanied by emission of radiation is traced back to the harmonic components into which the motion

of the atom may be resolved and which, according to the classical theory, determine the properties of the radiation to which the motion of the particles gives rise.

According to the correspondence principle, it is assumed that every transition process between two stationary states can be co-ordinated with a corresponding harmonic vibration component in such a way that the probability of the occurrence of the transition is dependent on the amplitude of the vibration. The state of polarisation of the radiation emitted during the transition depends on the further characteristics of the vibration, in a manner analogous to that in which on the classical theory the intensity and state of polarisation in the wave system emitted by the atom as a consequence of the presence of this vibration component would be determined respectively by the amplitude and further characteristics of the vibration.

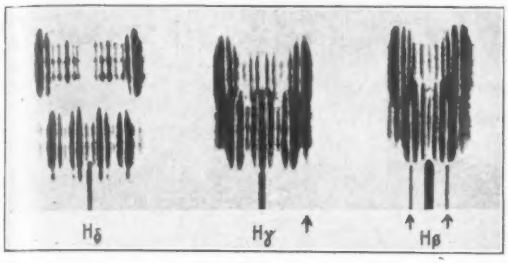

FIG. 6.

With the aid of the correspondence principle it has been possible to confirm and to extend the above-mentioned results. Thus it was possible to develop a complete quantum theory explanation of the Zeeman effect for the hydrogen lines, which, in spite of the essentially different character of the assumptions that underlie the two theories, is very similar throughout to Lorentz's original explanation based on the classical theory. In the case of the Stark effect, where, on the other hand, the classical theory was completely at a loss, the quantum theory explanation could be so extended with the help of the correspondence principle as to account for the polarisation of the different components into which the lines are split, and also for the characteristic intensity distribution exhibited by the components. This last question has been more closely investigated by Kramers, and the accompanying figure will give some impression of how completely it is possible to account for the phenomenon under consideration.

Fig. 6 reproduces one of Stark's well-known photographs of the splitting up of the hydrogen lines. The picture displays very well the varied nature of the phenomenon, and shows in how peculiar a fashion the intensity varies from component to component. The components below are polarised perpendicular to the field, while those above are polarised parallel to the field.

Fig. 7 gives a diagrammatic representation of the experimental and theoretical results for the line Hγ, the frequency of which is given by the Balmer formula with $n''=2$ and $n'=5$. The vertical lines denote the components into which the line is split up, of which the picture on the right gives the components which are polarised parallel to the field and that on the left those that are polarised perpendicular to it. The experimental results are represented in the upper half of the diagram, the distances from the dotted line representing the measured displacements of the components, and the lengths of the lines being proportional to the relative intensity as estimated by Stark from the blackening of the photographic plate. In the lower half is given for comparison a representation of the theoretical results from a drawing in Kramers' paper.

The symbol $(n'_{s'}-n''_{s''})$ attached to the lines gives the transitions between the stationary states of the atom in the electric field by which the components are emitted. Besides the principal quantum integer n, the stationary states are further characterised by a subordinate quantum integer s, which can be negative as well as positive and has a meaning quite different from that of the quantum number k occurring in the relativity theory of the fine structure of the hydrogen lines, which fixed the form of the electron orbit in the undisturbed atom. Under the influence of the electric field both the form of the orbit and its position undergo large changes, but certain properties of the orbit remain unchanged, and the subordinate quantum number s is connected with these. In Fig. 7 the position of the components corresponds to the frequencies calculated for the different transitions, and the lengths of the lines are proportional to the probabilities as calculated on the basis of the correspondence principle, by which also the polarisation of the radiation is determined. It is seen that the theory reproduces completely the main feature of the experimental results, and in the light of the correspondence principle we can say that the Stark effect reflects down to the smallest details the action of the electric field on the orbit of the electron in the hydrogen atom, even though in this case the reflection is so distorted that, in contrast with the case of the Zeeman effect, it would scarcely be possible directly to recognise the motion on the basis of the classical ideas of the origin of electromagnetic radiation.

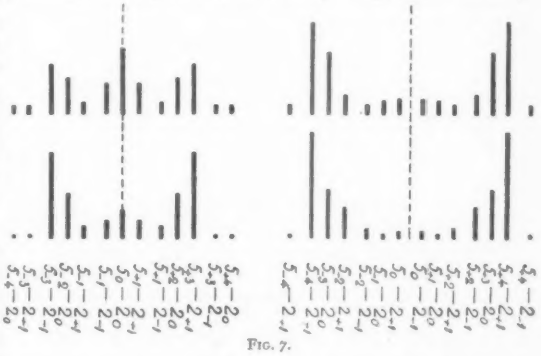

FIG. 7.

Results of interest were also obtained for the spectra of elements of higher atomic number, the explanation of which in the meantime had made important progress through the work of Sommerfeld, who introduced several quantum numbers for the description of the

electron orbits. Indeed, it was possible, with the aid of the correspondence principle, to account completely for the characteristic rules which govern the seemingly capricious occurrence of combination lines, and it is not too much to say that the quantum theory has not only provided a simple interpretation of the combination principle, but has further contributed materially to the clearing up of the mystery that has long rested over the application of this principle.

The same view-points have also proved fruitful in the investigation of the so-called band spectra. These do not originate, as do series spectra, from individual atoms, but from molecules; and the fact that these spectra are so rich in lines is due to the complexity of the motion entailed by the vibrations of the atomic nuclei relative to each other and the rotations of the molecule as a whole. The first to apply the postulates to this problem was Schwarzschild, but the important work of Heurlinger especially has thrown much light on the origin and structure of band spectra. The considerations employed here can be traced back directly to those discussed at the beginning of this lecture in connexion with Bjerrum's theory of the influence of molecular rotation on the infra-red absorption lines of gases. It is true we no longer think that the rotation is reflected in the spectra in the way claimed by classical electrodynamics, but rather that the line components are due to transitions between stationary states which differ as regards rotational motion. That the phenomenon retains its essential features, however, is a typical consequence of the correspondence principle.

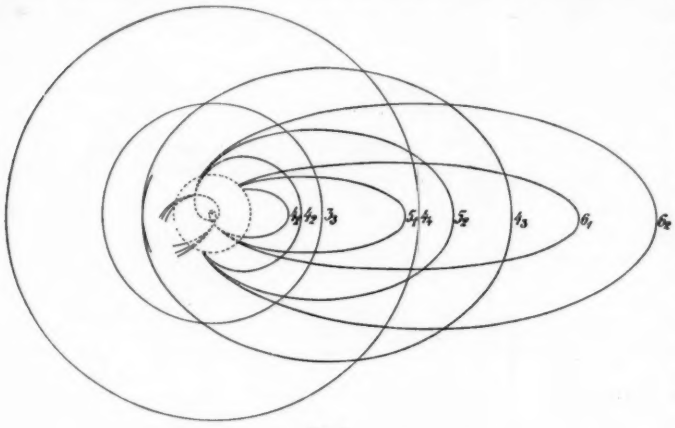

FIG. 8.

THE NATURAL SYSTEM OF THE ELEMENTS.

The ideas of the origin of spectra outlined in the preceding have furnished the basis for a theory of the structure of the atoms of the elements which has shown itself suitable for a general interpretation of the main features of the properties of the elements, as exhibited in the natural system. This theory is based primarily on considerations of the manner in which the atom can be imagined to be built up by the capture and binding of electrons to the nucleus, one by one. As we have seen, the optical spectra of elements provide us with evidence on the progress of the last steps in this building up process.

An insight into the kind of information that the closer investigation of the spectra has provided in this respect may be obtained from Fig. 8, which gives a diagrammatic representation of the orbital motion in the stationary states corresponding to the emission of the arc-spectrum of potassium. The curves show the form of the orbits described in the stationary states by the last electron captured in the potassium atom, and they can be considered as stages in the process whereby the 19th electron is bound after the 18 previous electrons have already been bound in their normal orbits. In order not to complicate the figure, no attempt has been made to draw any of the orbits of these inner electrons, but the region in which they move is enclosed by a dotted circle. In an atom with several electrons the orbits will, in general, have a complicated character. Because of the symmetrical nature of the field of force about the nucleus, however, the motion of each single electron can be approximately described as a plane periodic motion on which is superimposed a uniform rotation in the plane of the orbit. The orbit of each electron will therefore be to a first approximation doubly periodic, and will be fixed by two quantum numbers, as are the stationary states in a hydrogen atom when the relativity precession is taken into account.

In Fig. 8, as in Fig. 5, the electron orbits are marked with the symbol n_k, where n is the principal quantum number and k the subordinate quantum number. While for the initial states of the binding process, where the quantum numbers are large, the orbit of the last electron captured lies completely outside of those of the previously bound electrons, this is not the case for the last stages. Thus, in the potassium atom, the electron orbits with subordinate quantum numbers 2 and 1 will, as indicated in the figure, penetrate partly into the inner region. Because of this circumstance, the orbits will deviate very greatly from a simple Kepler motion, since they will consist of a series of successive outer loops that have the same size and form, but each of which is turned through an appreciable angle relative to the preceding one. Of these outer loops only one is shown in the figure. Each of them coincides very nearly with a piece of a Kepler ellipse, and they are connected, as indicated, by a series of inner loops of a complicated character in which the electron approaches the nucleus closely. This holds especially for the orbit with subordinate quantum number 1, which, as a closer investigation shows, will approach nearer to the nucleus than any of the previously bound electrons.

On account of this penetration into the inner region, the strength with which an electron in such an orbit is bound to the atom will—in spite of the fact that for the most part it moves in a field of force of the

same character as that surrounding the hydrogen nucleus—be much greater than for an electron in a hydrogen atom that moves in an orbit with the same principal quantum number, the maximum distance of the electron from the nucleus at the same time being considerably less than in such a hydrogen orbit. As we shall see, this feature of the binding process in atoms with many electrons is of essential importance in order to understand the characteristic periodic way in which many properties of the elements as displayed in the natural system vary with the atomic number.

In the accompanying table (Fig. 9) is given a summary of the results concerning the structure of

	1_1	$2_1 2_2$	$3_1 3_2 3_3$	$4_1 4_2 4_3 4_4$	$5_1 5_2 5_3 5_4 5_5$	$6_1 6_2 6_3 6_4 6_5 6_6$	$7_1 7_2$
1 H	1						
2 He	2						
3 Li	2	1					
4 Be	2	2					
5 B	2	2(1)					
– –	–	– –					
10 Ne	2	4 4					
11 Na	2	4 4	1				
12 Mg	2	4 4	2				
13 Al	2	4 4	2 1				
– –	–	– –	– –				
18 A	2	4 4	4 4				
19 K	2	4 4	4 4	1			
20 Ca	2	4 4	4 4	2			
21 Sc	2	4 4	4 4 1	(2)			
22 Ti	2	4 4	4 4 2	(2)			
– –	–	– –	– – –	–			
29 Cu	2	4 4	6 6 6	1			
30 Zn	2	4 4	6 6 6	2			
31 Ga	2	4 4	6 6 6	2 1			
– –	–	– –	– – –	– –			
36 Kr	2	4 4	6 6 6	4 4			
37 Rb	2	4 4	6 6 6	4 4	1		
38 Sr	2	4 4	6 6 6	4 4	2		
39 Y	2	4 4	6 6 6	4 4 1	(2)		
40 Zr	2	4 4	6 6 6	4 4 2	(2)		
– –	–	– –	– – –	– – –	–		
47 Ag	2	4 4	6 6 6	6 6 6	1		
48 Cd	2	4 4	6 6 6	6 6 6	2		
49 In	2	4 4	6 6 6	6 6 6	2 1		
– –	–	– –	– – –	– – –	– –		
54 X	2	4 4	6 6 6	6 6 6	4 4		
55 Cs	2	4 4	6 6 6	6 6 6	4 4	1	
56 Ba	2	4 4	6 6 6	6 6 6	4 4	2	
57 La	2	4 4	6 6 6	6 6 6	4 4 1	(2)	
58 Ce	2	4 4	6 6 6	6 6 6 1	4 4 1	(2)	
59 Pr	2	4 4	6 6 6	6 6 6 2	4 4 1	(2)	
– –	–	– –	– – –	– – – –	– – –	–	
71 Cp	2	4 4	6 6 6	8 8 8 8	4 4 1	(2)	
72 –	2	4 4	6 6 6	8 8 8 8	4 4 2	(2)	
– –	–	– –	– – –	– – – –	– – –	–	
79 Au	2	4 4	6 6 6	8 8 8 8	6 6 6	1	
80 Hg	2	4 4	6 6 6	8 8 8 8	6 6 6	2	
81 Tl	2	4 4	6 6 6	8 8 8 8	6 6 6	2 1	
– –	–	– –	– – –	– – – –	– – –	– –	
86 Em	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4	
87 –	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4	1
88 Ra	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4	2
89 Ac	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4 1	(2)
90 Th	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4 2	(2)
– –	–	– –	– – –	– – – –	– – –	– – –	–
118 ?	2	4 4	6 6 6	8 8 8 8	8 8 8 8	6 6 6	4 4

FIG. 9.

the atoms of the elements to which the author has been led by a consideration of successive capture and binding of electrons to the atomic nucleus. The figures before the different elements are the atomic numbers, which give the total number of electrons in the neutral atom. The figures in the different columns give the number of electrons in orbits corresponding to the values of the principal and subordinate quantum numbers standing at the top. In accordance with ordinary usage we will, for the sake of brevity, designate an orbit with principal quantum number n as an n-quantum orbit. The first electron bound in each atom moves in an orbit that corresponds to the normal state of the hydrogen atom with quantum symbol 1_1. In the hydrogen atom there is of course only one electron; but we must assume that in the atoms of other elements the next electron also will be bound in such a 1-quantum orbit of type 1_1. As the table shows, the following electrons are bound in 2-quantum orbits. To begin with, the binding will result in a 2_1 orbit, but later electrons will be bound in 2_2 orbits, until, after binding the first 10 electrons in the atom, we reach a closed configuration of the 2-quantum orbits in which we assume there are four orbits of each type. This configuration is met for the first time in the neutral neon atom, which forms the conclusion of the second period in the system of the elements. When we proceed in this system, the following electrons are bound in 3-quantum orbits, until, after the conclusion of the third period of the system, we encounter for the first time, in elements of the fourth period, electrons in 4-quantum orbits, and so on.

This picture of atomic structure contains many features that were brought forward by the work of earlier investigators. Thus the attempt to interpret the relations between the elements in the natural system by the assumption of a division of the electrons into groups goes as far back as the work of J. J. Thomson in 1904. Later, this view-point was developed chiefly by Kossel (1916), who, moreover, has connected such a grouping with the laws that investigations of X-ray spectra have brought to light.

Also G. R. Lewis and I. Langmuir have sought to account for the relations between the properties of the elements on the basis of a grouping inside the atom. These investigators, however, assumed that the electrons do not move about the nucleus, but occupy positions of equilibrium. In this way, though, no closer relation can be reached between the properties of the elements and the experimental results concerning the constituents of the atoms. Statical positions of equilibrium for the electrons are in fact not possible in cases in which the forces between the electrons and the nucleus even approximately obey the laws that hold for the attractions and repulsions between electrical charges.

The possibility of an interpretation of the properties of the elements on the basis of these latter laws is quite characteristic for the picture of atomic structure developed by means of the quantum theory. As regards this picture, the idea of connecting the grouping with a classification of electron orbits according to increasing quantum numbers was suggested by Moseley's discovery of the laws of X-ray spectra, and by Sommerfeld's work on the fine structure of these spectra. This has been principally emphasised by Vegard, who some years ago in connexion with investigations of X-ray spectra proposed a grouping of electrons in the atoms of the elements, which in many ways shows a likeness to that which is given in the above table.

A satisfactory basis for the further development of this picture of atomic structure has, however, only recently been created by the study of the binding

processes of the electrons in the atom, of which we have experimental evidence in optical spectra, and the characteristic features of which have been elucidated principally by the correspondence principle. It is here an essential circumstance that the restriction on the course of the binding process, which is expressed by the presence of electron orbits with higher quantum numbers in the normal state of the atom, can be naturally connected with the general condition for the occurrence of transitions between stationary states, formulated in that principle.

Another essential feature of the theory is the influence, on the strength of binding and the dimensions of the orbits, of the penetration of the later bound electrons into the region of the earlier bound ones, of which we have seen an example in the discussion of the origin of the potassium spectrum. Indeed, this circumstance may be regarded as the essential cause of the pronounced periodicity in the properties of the elements, in that it implies that the atomic dimensions and chemical properties of homologous substances in the different periods, as, for example, the alkali-metals, show a much greater similarity than that which might be expected from a direct comparison of the orbit of the last electron bound with an orbit of the same quantum number in the hydrogen atom.

The increase of the principal quantum number which we meet when we proceed in the series of the elements, affords also an immediate explanation of the characteristic deviations from simple periodicity which are exhibited by the natural system and are expressed in Fig. 1 by the bracketing of certain series of elements in the later periods. The first time such a deviation is met with is in the 4th period, and the reason for it can be simply illustrated by means of our figure of the orbits of the last electron bound in the atom of potassium, which is the first element in this period. Indeed, in potassium we encounter for the first time in the sequence of the elements a case in which the principal quantum number of the orbit of the last electron bound is, in the normal state of the atom, larger than in one of the earlier stages of the binding process. The normal state corresponds here to a 4_1 orbit, which, because of the penetration into the inner region, corresponds to a much stronger binding of the electron than a 4-quantum orbit in the hydrogen atom. The binding in question is indeed even stronger than for a 2-quantum orbit in the hydrogen atom, and is therefore more than twice as strong as in the circular 3_3 orbit which is situated completely outside the inner region, and for which the strength of the binding differs but little from that for a 3-quantum orbit in hydrogen.

This will not continue to be true, however, when we consider the binding of the 19th electron in substances of higher atomic number, because of the much smaller relative difference between the field of force outside and inside the region of the first eighteen electrons bound. As is shown by the investigation of the spark spectrum of calcium, the binding of the 19th electron in the 4_1 orbit is here but little stronger than in 3_3 orbits, and as soon as we reach scandium, we must assume that the 3_3 orbit will represent the orbit of the 19th electron in the normal state, since this type of orbit will correspond to a stronger binding than a 4_1 orbit. While the group of electrons in 2-quantum orbits has been entirely completed at the end of the 2nd period, the development that the group of 3-quantum orbits undergoes in the course of the 3rd period can therefore only be described as a provisional completion, and, as shown in the table, this electron group will, in the bracketed elements of the 4th period, undergo a stage of further development in which electrons are added to it in 3-quantum orbits.

This development brings in new features, in that the development of the electron group with 4-quantum orbits comes to a standstill, so to speak, until the 3-quantum group has reached its final closed form. Although we are not yet in a position to account in all details for the steps in the gradual development of the 3-quantum electron group, still we can say that with the help of the quantum theory we see at once why it is in the 4th period of the system of the elements that there occur for the first time successive elements with properties that resemble each other as much as the properties of the *iron group*; indeed, we can even understand why these elements show their well-known paramagnetic properties. Without further reference to the quantum theory, Ladenburg had on a previous occasion already suggested the idea of relating the chemical and magnetic properties of these elements with the development of an inner electron group in the atom.

I will not enter into many more details, but only mention that the peculiarities we meet with in the 5th period are explained in much the same way as those in the 4th period. Thus the properties of the bracketed elements in the 5th period as it appears in the table, depend on a stage in the development of the 4-quantum electron group that is initiated by the entrance in the normal state of electrons in 4_3 orbits. In the 6th period, however, we meet new features. In this period we encounter not only a stage of the development of the electron groups with 5- and 6-quantum orbits, but also the final completion of the development of the 4-quantum electron group, which is initiated by the entrance for the first time of electron orbits of the 4_4 type in the normal state of the atom. This development finds its characteristic expression in the occurrence of the peculiar family of elements in the 6th period, known as the *rare-earths*. These show, as we know, a still greater mutual similarity in their chemical properties than the elements of the iron family. This must be ascribed to the fact that we have here to do with the development of an electron group that lies deeper in the atom. It is of interest to note that the theory can also naturally account for the fact that these elements, which resemble each other in so many ways, still show great differences in their magnetic properties.

The idea that the occurrence of the rare-earths depends on the development of an inner electron group has been put forward from different sides. Thus it is found in the work of Vegard, and at the same time as my own work, it was proposed by Bury in connexion with considerations of the systematic relation between the chemical properties and the grouping of the electrons inside the atom from the point of view of Langmuir's static atomic model. While

until now it has not been possible, however, to give any theoretical basis for such a development of an inner group, we see that our extension of the quantum theory provides us with an unforced explanation. Indeed, it is scarcely an exaggeration to say that if the existence of the rare-earths had not been established by direct chemical investigation, the occurrence of a family of elements of this character within the 6th period of the natural system of the elements might have been theoretically predicted.

When we proceed to the 7th period of the system, we meet for the first time with 7-quantum orbits, and we shall expect to find within this period features that are essentially similar to those in the 6th period, in that besides the first stage in the development of the 7-quantum orbits, we must expect to encounter further stages in the development of the group with 6- or 5-quantum orbits. However, it has not been possible directly to confirm this expectation, because only a few elements are known in the beginning of the 7th period. The latter circumstance may be supposed to be intimately connected with the instability of atomic nuclei with large charges, which is expressed in the prevalent radioactivity among elements with high atomic number.

X-ray Spectra and Atomic Constitution.

In the discussion of the conceptions of atomic structure we have hitherto placed the emphasis on the formation of the atom by successive capture of electrons. Our picture would, however, be incomplete without some reference to the confirmation of the theory afforded by the study of X-ray spectra. Since the interruption of Moseley's fundamental researches by his untimely death, the study of these spectra has been continued in a most admirable way by Prof. Siegbahn in Lund. On the basis of the large amount of experimental evidence adduced by him and his collaborators, it has been possible recently to give a classification of X-ray spectra that allows an immediate interpretation on the quantum theory. In the first place it has been possible, just as in the case of the optical spectra, to represent the frequency of each of the X-ray lines as the difference between two out of a manifold of spectral terms characteristic of the element in question. Next, a direct connexion with the atomic theory is obtained by the assumption that each of these spectral terms multiplied by Planck's constant is equal to the work which must be done on the atom to remove one of its inner electrons. In fact, the removal of one of the inner electrons from the completed atom may, in accordance with the above considerations on the formation of atoms by capture of electrons, give rise to transition processes by which the place of the electron removed is taken by an electron belonging to one of the more loosely bound electron groups of the atom, with the result that after the transition an electron will be lacking in this latter group.

The X-ray lines may thus be considered as giving evidence of stages in a process by which the atom undergoes a ***reorganisation*** after a disturbance in its interior. According to our views on the stability of the electronic configuration such a disturbance must consist in the total removal of electrons from the atom, or at any rate in their transference from normal orbits to orbits of higher quantum numbers than those belonging to completed groups; a circumstance which is clearly illustrated in the characteristic difference between selective absorption in the X-ray region, and that exhibited in the optical region.

The classification of the X-ray spectra, to the achievement of which the above-mentioned work of Sommerfeld and Kossel has contributed materially, has recently made it possible, by means of a closer examination of the manner in which the terms occurring in the X-ray spectra vary with the atomic number, to obtain a very direct test of a number of the theoretical

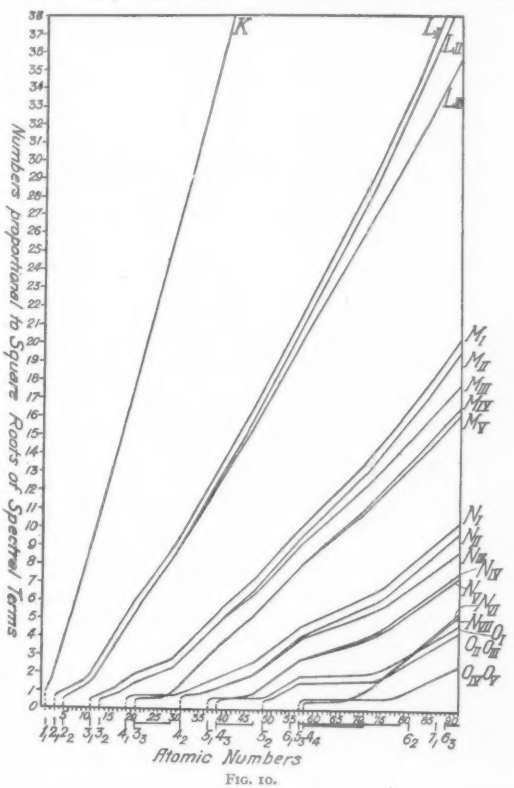

Fig. 10.

conclusions as regards the structure of the atom. In Fig. 10 the abscissæ are the atomic numbers and the ordinates are proportional to the square roots of the spectral terms, while the symbols K, L, M, N, O, for the individual terms refer to the characteristic discontinuities in the selective absorption of the elements for X-rays; these were originally found by Barkla before the discovery of the interference of X-rays in crystals had provided a means for the closer investigation of X-ray spectra. Although the curves generally run very uniformly, they exhibit a number of deviations from uniformity which have been especially brought to light by the recent investigation of Coster, who has for some years worked in Siegbahn's laboratory.

These deviations, the existence of which was not discovered until after the publication of the theory

of atomic structure discussed above, correspond exactly to what one might expect from this theory. At the foot of the figure the vertical lines indicate where, according to the theory, we should first expect, in the normal state of the atom, the occurrence of n_k orbits of the type designated. We see how it has been possible to connect the occurrence of every spectral term with the presence of an electron moving in an orbit of a definite type, to the removal of which this term is supposed to correspond. That in general there corresponds more than one curve to each type of orbit n_k is due to a complication in the spectra which would lead us too far afield to enter into here, and may be attributed to the deviation from the previously described simple type of motion of the electron arising from the interaction of the different electrons within the same group.

The intervals in the system of the elements, in which a further development of an inner electron group takes place because of the entrance into the normal atom of electron orbits of a certain type, are designated in the figure by the horizontal lines, which are drawn between the vertical lines to which the quantum symbols are affixed. It is clear that such a development of an inner group is everywhere reflected in the curves. Particularly the course of the N- and O-curves may be regarded as a direct indication of that stage in the development of the electron groups with 4-quantum orbits of which the occurrence of the rare-earths bears witness. Although the apparent complete absence of a reflection in the X-ray spectra of the complicated relationships exhibited by most other properties of the elements was the typical and important feature of Moseley's discovery, we can recognise, nevertheless, in the light of the progress of the last years, an intimate connexion between the X-ray spectra and the general relationships between the elements within the natural system.

Before concluding this lecture I should like to mention one further point in which X-ray investigations have been of importance for the test of the theory. This concerns the properties of the hitherto unknown element with atomic number 72. On this question opinion has been divided in respect to the conclusions that could be drawn from the relationships within the periodic table, and in many representations of the table a place is left open for this element in the rare-earth family. In Julius Thomsen's representation of the natural system, however, this hypothetical element was given a position homologous to titanium and zirconium in much the same way as in our representation in Fig. 1. Such a relationship must be considered as a necessary consequence of the theory of atomic structure developed above, and is expressed in the table (Fig. 9) by the fact that the electron configurations for titanium and zirconium show the same sort of resemblances and differences as the electron configurations for zirconium and the element with atomic number 72. A corresponding view was proposed by Bury on the basis of his above-mentioned systematic considerations of the connexion between the grouping of the electrons in the atom and the properties of the elements.

Recently, however, a communication was published by Dauvillier announcing the observation of some weak lines in the X-ray spectrum of a preparation containing rare-earths. These were ascribed to an element with atomic number 72 assumed to be identical with an element of the rare-earth family, the existence of which in the preparation used had been presumed by Urbain many years ago. This conclusion would, however, if it could be maintained, place extraordinarily great, if not unsurmountable, difficulties in the way of the theory, since it would claim a change in the strength of the binding of the electrons with the atomic number which seems incompatible with the conditions of the quantum theory. In these circumstances Dr. Coster and Prof. Hevesy, who are both for the time working in Copenhagen, took up a short time ago the problem of testing a preparation of zircon-bearing minerals by X-ray spectroscopic analysis. These investigators have been able to establish the existence in the minerals investigated of appreciable quantities of an element with atomic number 72, the chemical properties of which show a great similarity to those of zirconium and a decided difference from those of the rare-earths.[2]

I hope that I have succeeded in giving a summary of some of the most important results that have been attained in recent years in the field of atomic theory, and I should like, in concluding, to add a few general remarks concerning the view-point from which these results may be judged, and particularly concerning the question of how far, with these results, it is possible to speak of an explanation, in the ordinary sense of the word. By a theoretical explanation of natural phenomena we understand in general a classification of the observations of a certain domain with the help of analogies pertaining to other domains of observation, where one presumably has to do with simpler phenomena. The most that one can demand of a theory is that this classification can be pushed so far that it can contribute to the development of the field of observation by the prediction of new phenomena.

When we consider the atomic theory, we are, however, in the peculiar position that there can be no question of an explanation in this last sense, since here we have to do with phenomena which from the very nature of the case are simpler than in any other field of observation, where the phenomena are always conditioned by the combined action of a large number of atoms. We are therefore obliged to be modest in our demands and content ourselves with concepts which are formal in the sense that they do not provide a visual picture of the sort one is accustomed to require of the explanations with which natural philosophy deals. Bearing this in mind I have sought to convey the impression that the results, on the other hand, fulfil, at least in some degree, the expectations that are entertained of any theory; in fact, I have attempted to show how the development of atomic theory has contributed to the classification of extensive fields of observation, and by its predictions has pointed out the way to the completion of this classification. It is scarcely necessary, however, to emphasise that the theory is yet in a very preliminary stage, and many fundamental questions still await solution.

[2] For the result of the continued work of Coster and Hevesy with the new element, for which they have proposed the name hafnium, the reader may be referred to their letters in NATURE of January 20, February 10 and 24, and April 7.

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Muscular Exercise.[1]

By Prof. A. V. Hill, F.R.S.

Introduction.—Muscular exercise is a subject in which most people are interested. It is fortunate therefore that, in this direction, physiology has made greater progress into the intimate working of the body than perhaps in any other. The means by which bodily movements are carried out is muscle. Muscle is the red meat. There are three kinds of muscles: the voluntary muscle of the trunk and limbs, governed—or at any rate governable—by the conscious will of the individual; the involuntary muscle of the blood-vessels, of the alimentary and excretory, the so-called vegetative, system; and the cardiac or heart muscle, the muscle which pumps the blood round the body.

Muscle from the microscopic point of view is made up of a large number of similar thin fibres, about $\frac{1}{500}$ inch in diameter, and made of a jelly-like substance, running more or less parallel to one another. They are liberally supplied with minute blood-vessels from which they obtain their supplies of oxygen and food.

The voluntary muscle fibre is long and regular, and has obvious and characteristic cross-striations. The involuntary muscle fibre is smooth and long, with obvious nuclei, and generally occurs in thin sheets. It shows no sign of cross-striations. The heart muscle is vividly cross-striated, but its fibres are shorter and connected physiologically with one another, not running regularly in considerable lengths, their directions corresponding to the lines in which the walls of the heart are required to shorten, in order to expel the blood efficiently.

The voluntary muscle is excited by a voluntary, a so-called medullated nerve: the involuntary muscle by an involuntary, a non-medullated nerve: the heart beats automatically of itself, though its beats can be influenced reflexly through two nerves.

In function the muscles differ very widely from one another. The voluntary muscle moves very rapidly, indeed in some small animals the rapidity of its response is almost incredible—one knows the amazing quickness of a little bird jumping from twig to twig, but this is as nothing compared with the speed with which some small insects move their wings, a speed which one can detect from the high-pitched note they emit. The voluntary muscle is very powerful; it is usually "geared up" to increase the quickness of movement of the limb to which it is attached; if the flexor muscles of the arm of a powerful man were connected directly to a heavy load, they could lift a weight of about half a ton.

The voluntary muscle is very efficient for movements of moderate speed: it is very wasteful, however, if used to maintain a force for a long time, or if required to contract, either very rapidly or very slowly. The involuntary muscle, on the other hand, moves only very slowly: it takes seconds to perform what a voluntary muscle can do in a few tenths or hundredths of a second; it is very economical, however, in maintaining a force for minutes, or hours, for intervals maybe thousands of times longer than would be enough to produce complete fatigue in a voluntary muscle. The heart muscle moves at an intermediate speed: in man from 40 to 200 times a minute, depending on his health and training and state of exercise: in little animals faster, in large animals slower: it beats only—it never maintains a contraction—it would, so to speak, lift a weight up and down, but it could never keep it supported: it is amazingly infatiguable—it has a first call on the oxygen of the blood, and it can perform the most prodigious athletic feats.

A muscle's function is to "contract." The word contraction—drawing together—very well defines the activity of muscle: its volume does not alter when it contracts: like a piece of elastic it merely draws—or attempts to draw—its ends together. The sheaths of the muscle fibres are continued as tendons, and these tendons are attached to bones, so that when the muscle draws together the bones revolve about their common joint, and movements are produced. In heart muscle, the whole organ, in the form of two pumps, with inlet and outlet holes and suitable valves, is simply a closed vessel with powerful contractile walls which—by their drawing together—expel the blood into the arteries and around the body.

The fibres of voluntary muscle are bound together into anatomical and functional bundles—the so-called muscles—doing special duties in special ways and in special distributions. If a muscle be required to move through a long distance its fibres are parallel to the length of the muscle and long: if it be required to

[1] Discourse delivered at the Royal Institution on Friday, February 16.

move only through a short distance, but to exert a more powerful pull, its fibres run partly across the length of the muscle, they are shorter, and there are more of them: length of movement is sacrificed to strength.

Nervous Control.—The muscles have their activities controlled and co-ordinated by the nervous system. Partly this co-ordination is conscious and voluntary; mainly, however, it depends upon involuntary reflex control. In the body, in addition to the ordinary sense-organs is a complex and very important sensory system — the proprioceptive system — which deals mainly, or only, with the position, translation, and rotation of the body, with the stresses and strains in the muscles, with the positions and movements of the limbs. This system keeps the nervous system informed about the movements, passive or active, of the body, and about the strains and stresses, passive or active, of the muscles: and when anything happens, with amazing rapidity and almost unerring accuracy, the appropriate reaction is made, so that the balance or the posture is maintained, the integrity of the body is safeguarded, and the end in view is reached. Efficiency and skill at games, power and economy in violent effort, the faculty, in the literal sense, of falling on one's feet, all depend upon these quick, silent, overmastering, and generally unconscious reactions, dictated by the nervous system on the receipt of urgent messages from tendons, joints and muscles, or from the little sense organs associated with the ear.

Skill, power, and economy of muscular effort depend upon the effectiveness of these reactions; partly this muscular sense can be acquired, partly it is inborn, partly it is conscious or semi-conscious (though always inarticulate), partly it is reflex and instinctive: in any case it represents a highly developed and a very beautiful and important property of the nervous system. The instinctive skill, quickness, and economy of the gymnast or climber, of the mechanic, airman, tennis player, or athlete, depend upon a vivid and readily reproducible picture in the brain or nervous system, *a picture*, as Pear puts it, *of muscular exercise in terms of the sensations which effective and successful movements produce*. This lecture is intended to deal more particularly with quite another aspect of muscular exercise. To stress the energetic side of exercise, however, without any note on its intellectual and co-ordinative side, would give quite a false impression of the interest and variety of the subject.

Energetics.—Let us turn now to what one may call the energetics of muscular activity, of the capacity for doing work, or producing movement, of the cost of that work—of what we call "efficiency"—and of the conditions which limit that capacity—of what we call "fatigue." When a muscle contracts it can do work, which can be measured in gm. cm., or in ft. lb. This capacity for doing work seemed to physiologists to be the primary thing, until it was realised comparatively lately that *force*, rather than *work*, is the fundamental product of muscle. To maintain a state of contraction—even when no work in the mechanical sense is being done, as, for example, in pushing an immovable object, or in holding a weight at a fixed level—is just as tiring and expensive as actually to do mechanical work. The function of a muscle, therefore, is to pass from one state of stress to another state of stress without necessarily altering its length at all: if its load, or the resistance to its motion, be such that the muscle can shorten when its tension rises, it will of course do work in the mechanical sense: if, however, it maintain its state of tension without shortening at all, it will, none the less, require energy and become fatigued. Indeed, one knows that the most fatiguing exercise is to hold something, say at arm's length, without moving it up or down, without therefore doing any work at all in the mechanical sense.

Isolated Muscle.—Fortunately, for physiology, muscles can be isolated, and made to continue their function of contracting for days after removal from the body. It is easy to keep a frog's isolated muscle alive, in the sense at any rate that it will react to a stimulus, for many days. Moreover, the chief function of a muscle, indeed in a cold-blooded animal the only function, is simple and easy to detect and measure: the function of movement, of maintaining a posture, of exerting a force, is so extremely important to the animal that a very large proportion of its body has been devoted to this single highly differentiated purpose. Fortunately also it is easy to apply an artificial stimulus to a muscle, the electric shock, which produces no injurious effects and leaves the muscle ready to react again in a similar way a large number of times. A single sharp burst of electric current excites the muscle fibre to give the simplest and most fundamental unit of physiological response, the muscle twitch. In a twitch the tension rises, attains a maximum, and then falls again to zero, the whole cycle occupying anything from a small fraction of a second up to several seconds, depending upon the nature and condition of the muscle.

Now, in a voluntary muscle it is often—indeed almost always—necessary to maintain a force, or to exert a pull, for a finite and determinate time, not simply to give a tug and have done: and in such muscle this continuous pull can be produced by a rapid succession of stimuli each occurring before the effect of the previous one has passed off. One's own muscles do not appear to be obviously unsteady when exerting a voluntary effort: it can easily be shown,

however, by a delicate electrical device that 40 to 50 obvious vibrations per second occur in them, and that they are really reacting discontinuously to a rapid stream of stimuli: even the shortest voluntary contraction of which the human muscles are capable is due to a volley of impulses shot at it, along the nerves, by the brain. Each separate unit of effort, however, which goes to make up the complete contraction is expensive—each requires energy just as each stroke with a pump requires energy. It is obvious, therefore, why the *maintenance* of contraction is expensive and fatiguing.

Fatigue.—Nearly all the recent and important advances in muscle physiology have resulted from a study of the phenomena of fatigue. We all know that there is a limit to muscular exertion, a limit which is set by what we call fatigue. If an able-bodied man take exercise at a very small rate, *e.g.* by walking, he remains comparatively untired for long periods: if he takes exercise more violently he becomes tired more quickly: if he exerts himself with the extreme effort of which he is capable, he is completely exhausted in less than a minute. There are many different kinds of fatigue, but the one we are discussing now, from the study of which so much light has been shed on the nature of muscles, is the extreme athletic fatigue which results rapidly from very violent effort. By it the finest athlete in the world may be overcome within a minute. It is a simple and comparatively intelligible thing. We can reproduce it readily in isolated muscle, deprived of its circulation. Let us subject an isolated frog's muscle, every second or two, to an electric shock, and record its contraction · we find that the response changes in a regular and progressive way, the force exerted becoming less, the contraction being developed rather more slowly and continuing much longer, relaxation being much drawn out. Finally, the muscle becomes inexcitable. Now in the intact animal, in man, we know that even extreme fatigue is rapidly recovered from, and this recovery is attributed to the circulation. If the circulation be hindered by a cramped position recovery is slower. If the fatigued isolated muscle be left in a chamber free of oxygen, no sign of recovery occurs: if, however, it be left in oxygen, in a few hours complete recovery will take place, and the muscle will now be capable of repeating its previous effort.

The realisation, especially by Fletcher about twenty-five years ago, of the extreme importance of this observation led directly to the most striking advances in our knowledge of the working of muscle. Recovery from fatigue is possible only in the presence of oxygen, and it was natural to suppose that the oxygen was used to oxidise some waste product, the presence of which acted unfavourably on the muscle. The next great step was due again in part to Fletcher, this time in co-operation with Hopkins. Lactic acid was known to occur in muscle, and Fletcher and Hopkins found the lactic acid to be increased by exercise, and diminished or abolished by recovery in the presence of oxygen. Furthermore, there appeared to be a certain definite maximum, beyond which the lactic acid content of the muscle could not be driven, even by the most vigorous stimulation: clearly this corresponded to the maximum effort a muscle could make. What was the function of this lactic acid, was it indeed to be the keystone of the bridge which physiologists were building from physics and chemistry on one hand to muscular activity on the other?

Heat-production.—Muscles, in activity, give out heat. External mechanical work is produced by the muscle with an efficiency of only about 25 per cent. Hence for every 25 ft. lb. of energy turned into external mechanical work at least 75 ft. lb. are degraded into heat inside the body. In a maintained contraction, in which no actual work is done, all the energy used is turned into heat: while in such movements as running, the energy is indeed turned in part into kinetic energy, which, however, is chiefly reabsorbed into the body as heat, owing to the jolts and jerks and rapid movements of the limbs, just as the energy of a motor car on a bumpy road is absorbed largely as heat in the tyres. In a single muscle twitch the rise of temperature is only about 0·003° C., and if one wishes to measure to 1 per cent.—and for some purposes one must measure to 0·1 per cent.—it is necessary to read to the nearest 0·00003° C. This can, however, be done, and with the wonderful electrical measuring instruments now available it has become comparatively easy. It is worth doing, because the heat accompanies, and is a measure of, the chemical processes occurring in muscular activity, and its production can be followed continuously, and so made to give us the time course of those chemical processes.

If the electrical record of the thermal response of the muscle to stimulation be carefully analysed, it is found that the heat-production is by no means simple in its time relations. In the first place, if the muscle be in oxygen, there is an evolution of heat lasting for many minutes after the contraction is over: and this evolution of heat is not small, but actually larger in total extent than the heat which occurs early in the contraction. In the absence of oxygen this delayed heat almost disappears. Clearly it is somehow connected with the recovery process Fletcher had noticed in an exhausted muscle, which we all know in our own bodies; it is accompanied, as Fletcher and Hopkins had shown, by a disappearance of lactic acid. The recovery heat-production occurs more

rapidly at a higher pressure of oxygen. This agrees with what we know of recovery from exertion, or exhaustion, in man: breathing pure oxygen, instead of air, enormously increases its speed and completeness. Moreover, the magnitude of the recovery heat-production told one what happened to the lactic acid in recovery. One knew how much lactic acid was produced in a given contraction; one knew, therefore, how much lactic acid was removed in the complete recovery from that contraction: if it were all oxidised the heat evolved could be calculated: actually the amount observed is only about 1/6th of the amount calculated: hence the lactic acid removed in recovery, or at any rate its chief part, is not removed by oxidation, but in some other way.

Apart from this delayed heat-production associated with recovery, one might have expected the rest of the heat to be given out rapidly, more or less ex-

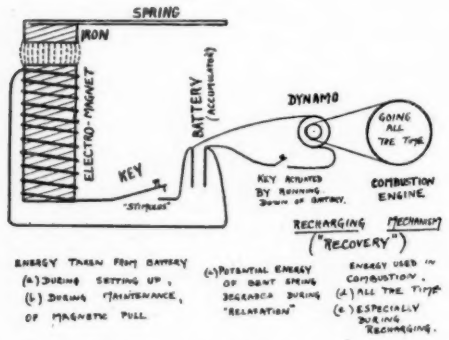
SPRING
IRON
ELECTRO-MAGNET
BATTERY (ACCUMULATOR)
DYNAMO
GOING ALL THE TIME
KEY
KEY ACTUATED BY RUNNING DOWN OF CLOCK.
COMBUSTION ENGINE.
RECHARGING MECHANISM ("RECOVERY")
ENERGY TAKEN FROM BATTERY (a) DURING SETTING UP, (b) DURING MAINTENANCE, OF MAGNETIC PULL
(c) POTENTIAL ENERGY OF BENT SPRING DEGRADED DURING "RELAXATION"
ENERGY USED IN COMBUSTION. (d) ALL THE TIME (e) ESPECIALLY DURING RECHARGING.

FIG. 1.—Electromagnetic analogy to the working of muscle.

plosively, at the commencement of contraction. Contraction has been likened to the explosion of a cartridge: the muscle suddenly gives out heat and develops force. This force, however, represents a state of elastic potential energy in the muscle, and when the muscle relaxes this potential energy disappears, and we should expect it to reappear as heat. Actually the analysis of the heat-production in the single twitch shows that about 60 per cent. of it is evolved in the initial process of setting up the contraction, 40 per cent. of it in the final stage of relaxation. If the contraction be prolonged, there is in addition a prolonged evolution of heat, lasting as long as the contraction, the rate of heat-production being proportional to the force maintained.

There are, therefore, four phases in the heat-production of muscle, corresponding (1) to the development, (2) to the maintenance, and (3) to the disappearance of the response, and finally (4) to recovery therefrom. A simple physical picture of the system is given (Fig. 1) by an electromagnet, pulling on a piece of iron attached to a spring: a key: a battery: and a dynamo (driven by a combustion engine of some kind) to recharge the latter. Energy is consumed in setting up the pull of the electromagnet, energy is being consumed all the time in maintaining the pull, energy—the potential energy of the magnetic field and the spring—is liberated when the current is broken, and energy is used in recharging the battery.

This picture has recently been given a more concrete chemical form. In contraction the lactic acid comes from glycogen; in recovery the lactic acid is restored as the glycogen from which it came, apart from a small proportion—about $\frac{1}{6}$th—which is oxidised to provide energy for the restoration. In the setting up of the contraction, therefore, lactic acid is liberated; in relaxation it is neutralised: it somehow produces the mechanical response by the action of its acidic part upon the structural protein elements of the muscle fibre. Protein is a weak acid at the hydrogen ion concentration of the body, and the structural elements of the muscle are in effect highly ionised sodium (or potassium) salts of protein. These structures therefore have a negative electric charge, all along their length, each element of the structure repelling every other element. The localised production of lactic acid causes the formation of sodium (or potassium) lactate, and of undissociated protein acid: the protein structure is discharged electrically: its elements cease to repel each other, and shortening occurs. It is well known that if the surface charge of mercury, in contact with sulphuric acid, be changed by conduction from outside, there results a change of surface tension, and so a movement of the mercury. This principle is utilised in the capillary electrometer, and would seem to have been employed by Nature in the muscle. The heat associated with contraction is due to the chemical formation of lactic acid from glycogen. As soon, however, as the lactic acid is free it is neutralised by the alkalies of the muscle, and relaxation sets in, the heat produced in relaxation being due to the chemical process of neutralisation. To maintain a contraction therefore requires a balance between the rate at which lactic acid is produced and the rate at which it is neutralised. Finally, in recovery, the neutralised lactic acid is slowly removed and restored, by the working of some unknown recovery mechanism, by which 5 parts of it are restored, and 1 part oxidised to supply the necessary energy.

Exercise in Man.—Our knowledge of the nature of muscular work in man has been derived largely from a study of the amount of oxygen used, and the various characteristics and time-relations of the oxygen supply. The subject of the experiment carries a large bag on his back (Fig. 2) and by means of a mouthpiece containing two valves, and a pipe and tap, he can breathe

in fresh air from the outside atmosphere and expire it all automatically into the bag. A sample of the expired air can be collected for any desired interval. An analysis of it, a measurement of its volume, and a knowledge of the composition of the inspired air, allow a determination of the oxygen taken in and the

FIG. 2.—Bag, pipe, tap, valves, and mouthpiece used to investigate the gaseous exchanges of man during running.

carbon dioxide produced. From these the amount of energy used by the man during the period in question can be calculated. A point immediately brought out is (as in the isolated muscle) that the oxygen must be regarded, not as being used during the actual exercise itself, but in recovery, each element of the oxygen

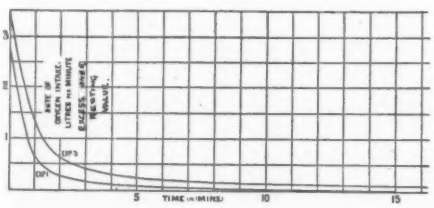

FIG. 3.—Oxygen intake in recovery after exercise: exercise ends at time o.

consumption corresponding to recovery from a previous element of the exercise (Fig. 3).

Many kinds of exercise have been investigated, for example bicycling, swimming, climbing, walking, running, ski-ing, and skating, and even the laborious process of pushing a motor bicycle up a hill! The two main types of muscular exercise are: (*a*) very violent exercise lasting for a short time, and (*b*) prolonged exercise of a more moderate kind.

Violent Exercise.—Let us take first the case of very severe exercise, for example, that of a man running 100 yards at top speed. The first personal impression which one forms of such severe exercise is that immediately after it, and often for a comparatively long time after it, panting occurs. The oxygen taken in is used almost entirely in recovery. In one experiment a good runner ran 225 yards in $23\frac{2}{5}$ seconds, and in the succeeding quarter of an hour recovered from his effort and used an extra $8\frac{3}{4}$ litres of oxygen in so doing. Such exercise, if it *could* be continued indefinitely, would require about 22 litres of oxygen every minute, but from other experiments the subject is known to be incapable of taking in more than about 4 litres per minute. Hence, during the most violent effort of which he was capable, he was using energy at about $5\frac{1}{2}$ times the rate that would have been possible had it been necessary for him to depend upon a contemporary supply of oxygen.

The "record" is held by a man of 46, who by means of a rapid quarter-of-a-mile run, followed by violent gymnastic exercise for 30 seconds, succeeded in making himself so exhausted that $13\frac{1}{4}$ litres of oxygen had to be used in recovery. This amount of oxygen would have maintained him quietly in bed for about an hour! It is clear that the body can get energy "on credit," which it has to repay after the exercise is over, by taking in later an extra amount of oxygen. It acts in the same manner as an accumulator, which can be run down at a very high rate for a short time and recharged afterwards. The discharge process is the formation of lactic acid from glycogen: in recovery this is reversed, the energy for the reversal being provided by combustion. The maximum lactic acid production in the muscle determines the limits of exercise, and the magnitude of the "maximum oxygen debt."

Prolonged Exercise.—Let us now discuss the case of exercise continued for a long time. By the most extreme effort of the respiratory system, a healthy man can take in about 4 litres of oxygen every minute. Consider, then, the case of a man taking exercise for a long time, say for an hour, during which time he will take in and use anything from 150 to 240 litres of oxygen. An oxygen "credit" even of $13\frac{1}{4}$ litres is only a small fraction of the oxygen which he can actually take in during the hour of exercise. Hence, he is limited in such types of exercise, not by the magnitude of the "debt" to which the body can submit, not, that is to say, by the lactic acid maximum of his muscles, but chiefly by the maximum rate at which he can take in oxygen. The oxygen is brought to the

lungs by the movements of respiration, thence diffuses through the lungs into the blood, which is pumped round the body to the active limbs and muscles. The amount of oxygen, however, which can be carried by the blood is comparatively small, namely, only about $\frac{1}{3}$th of its total volume.

The efficiency of the mechanism by which the oxygen is carried round in the circulating blood depends very largely on the efficiency and capacity of the heart. For prolonged vigorous exercise a powerful and efficient heart is essential. If, however, the lungs be too small the oxygen pressure in them will fall too rapidly when a given amount of oxygen is carried away by the blood, and the smaller the lungs the shorter will be the time (for a given blood-flow) during which each drop of blood lingers in them in contact with the air. The smaller the lungs, therefore, the less opportunity will the blood have of collecting its required oxygen: the smaller the lungs and the less efficient their ventilation, the lower will be the pressure of oxygen in the arterial blood.

Now the heart is an extremely vigorous and hard-working organ, and it has the first call upon the oxygen which is carried by the blood. The coronary artery takes blood directly from the aorta, and carries it round the heart muscle itself. If the lungs be small, or their ventilation inadequate, or their walls too impermeable, the pressure of oxygen in the arterial blood will begin to fall; consequently the heart itself will get a lower pressure of oxygen—it will slow up or give a less effective beat, the blood-flow will be slowed, and the oxygen pressure in the blood will rise again to another higher value. Thus a balance will be reached in which each unit in the double mechanism is working at its limiting capacity, and one will find in athletes, who are capable of long-continued effort, that there is a combination of (*a*) a vigorous and efficient heart, and (*b*) capacious lungs capable of rapid and extensive ventilation.

A vigorous output of blood by the heart requires a vigorous return of blood to the heart. On the venous side of the small capillaries which feed the muscles with oxygen, there is little pressure left to drive the blood along to the heart. In the veins, therefore, the flow of blood is largely determined by the activity and movements of the body. The veins are provided with valves, and the alternating movements of the limbs and muscles help to pump the blood along the veins. If the body be rigid the arteries and capillaries are constrained and the blood-flow is hindered, while the veins get none of the rhythmic changes of pressure which tend to pump the blood along them, and so they fail to supply the heart with blood. Such exercise as holding oneself up with arms bent, in a gymnasium, on a pair of rings, is not in itself violent, and would not, if it *could* be continued, require an amount of oxygen comparable with running, even at so slow a pace as eight miles an hour. In such exercise, however, an extremely violent contraction in the very muscle that requires the energy almost entirely prevents the supply of blood to it, no oxygen is received, lactic acid rapidly accumulates, and exhaustion sets in.

Similarly, in such types as rowing, in which part of the body is in a state of stress during a large part of the time and the rhythmic movements are relatively slow, the supply of oxygen is more difficult. Consequently rowing appears to strain the heart more often than other kinds of athletic effort. For an easy and vigorous circulation no exercise seems to compare with running on the flat; here the movements are very rapid and the muscles are rigid during only a fraction of each cycle; consequently the blood can run through very easily, and it gets helped along in the veins by the jolts and jerks and shakes which the body receives, and by the rapid rhythmic pressures which are applied to the veins by the movements of the limbs. Thus from the point of view of taking as much exercise in a given time, with as little strain on the heart as possible, running is probably superior in type to any kind of exercise.

The function of the heart in exercise is so important that a vivid appreciation is desirable of the extraordinary tasks it sometimes undertakes. A subject of $11\frac{1}{2}$ stone weight succeeded in taking in about 4·2 litres of oxygen in a minute, while running round a track at about 9 miles per hour carrying a bag and breathing through valves and mouth-piece. Now the amount of oxygen which the blood can take in and give out, as it circulates once through the body, is certainly not more than about $\frac{1}{4}$th of its own volume. Hence at least 7 times 4·2 litres of blood per minute, *i.e.* about 30 litres, were circulating round his body during this experiment. The largest water-tap in an ordinary house has an output which is poor when compared with that of a human heart. It is little wonder that the heart goes wrong sometimes: the wonder is that this happens relatively so seldom.

An Example from Athletics.—The way in which the capacity of the body for exercise depends upon the supply of oxygen, actual or potential, can be illustrated by an example from athletics. A certain subject is capable of taking in about 4·2 litres of oxygen per minute; let us assume that his maximum oxygen credit is 13·2 litres, as found by Lupton in another subject. Suppose that at the end of a race his oxygen supply, actual or potential, is completely exhausted. Then clearly if he runs for a minute he has $(4{\cdot}2 + 13{\cdot}2) = 17{\cdot}4$ litres to spend altogether: if he runs for two minutes $(2 \times 4{\cdot}2 + 13{\cdot}2) = 21{\cdot}6$ litres altogether, or 10·8

litres per minute: if for five minutes, 34·2 litres altogether, or 6·8 litres per minute. The reason why he can run faster in a short race than in a long one is that his average rate of expenditure of oxygen can be higher. Now the following table gives the best performances, at various flat distances, of this subject, together with calculations therefrom, on the above assumptions:

Distance.	¼ mile.	½ mile.	¾ mile.	1 mile.	2 miles.
Time	53 sec.	1 m. 17 s.	2 m. 3 s.	4 m. 45 s.	10 m. 30 s.
Average speed, metres per min.	455	419	392	339	306
Oxygen available in this time (lit.)	17	18·6	21·8	33·1	57·3
Oxygen requirement per min. at this speed (lit.)	19·2	14·5	10·6	7·0	5·5

If, therefore, the maximum rate at which a fit man can run a given distance does depend only upon the amount of oxygen he can obtain (*a*) out of income

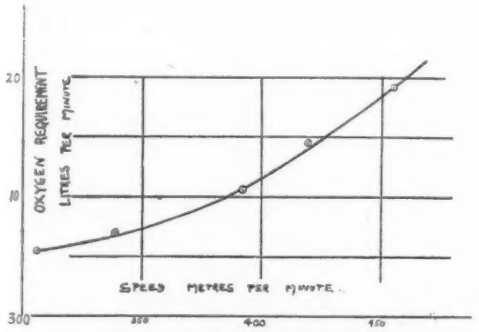

FIG. 4.—Oxygen requirement per minute for running at different speeds: *calculated* from the data in the previous Table.

through the lungs and circulation, and (*b*) on credit, then, knowing the maximum intake and the maximum credit, one can calculate the requirement at the different speeds. Running at 306 metres per minute, apparently about 5·5 litres of oxygen per minute were required; at high speeds much more; at the highest speeds enormously more (Fig. 4).

It is instructive therefore to inquire, by direct experiment, whether the oxygen requirement of running really has the value we have calculated, whether it really rises so rapidly as the speed of running is increased. The oxygen can be measured as before. It is necessary to take into account not only the oxygen actually taken in, but also the increase in the oxygen debt during the period of running. The subject stands at rest and measures his resting oxygen consumption; he runs 100 yards at the required speed; during the run and in the following fifteen minutes his oxygen intake is measured; from this is subtracted the oxygen he would have used had he remained at rest the whole time; the remainder is the oxygen consumption due to the exercise, during and in complete recovery from it. The result is exactly as shown in the figure: the measured oxygen requirement rises continuously as the speed is increased, attaining enormous values at the highest speeds. Hence we may conclude that the maximum time for which an effort of given severity can be maintained is determined mainly by considerations of the oxygen supply, actual or potential, to the active muscles.

Economy of Movement.—This leads us to the important practical question of what is called the "efficiency" of movement. Clearly if a given movement can be carried out more economically, *i.e.* at the expense of less energy, then less oxygen will be required for it, and its maximum duration can be increased. It seems probable that the difference between a good long-distance runner and a bad one may often be due, not to the fact that the good runner has a more effective mechanism for supplying his muscles with oxygen, but rather to the fact that he carries out his movements with greater economy. In any category of muscular effort the unpractised person will use inappropriate muscles and movements, or will use the appropriate muscles with an inappropriate force or rhythm. Some people's nervous systems are naturally athletic: the pictures they form of muscular movement, in terms of the sensations which it gives them, are clear, vivid, and sharp: they realise easily, from its subjective aspects, the most economical, the most effective, and the most convenient manner in which to employ and co-ordinate their various muscles, both in the power, the phase, and the rhythm of their several responses. Other people are clumsy, ineffective, and uneconomical.

If the timing of the valves of a motor, or the timing of the spark, be wrong, or if the valve clearance be not correct, the efficiency drops; so it is in an animal: if the muscles do not react with one another in the right phase, with exactly the requisite force, and in the appropriate rhythm, the movement becomes uneconomical. This economy of effort can, in part, be taught: but just as all the practice in the world will not turn some quite intelligent people into mathematicians, so all the practice in the world may never turn some quite powerful and well-developed people into first-class athletes. Training and practice are essential, but they can only build on an aptitude already there. If a subject use his muscles uneconomically, if—so to speak—the timing and clearance of his valves be wrong, he will need an excessive supply of oxygen. Consequently he will be an ineffective athlete, or an ineffective workman: he is uneconomical. Athletic

prowess depends not only upon a large oxygen supply, but upon a low oxygen requirement.

Mechanical Efficiency.—Finally, let us consider the "mechanical efficiency" of muscular movement in its more technical sense, of work done divided by energy utilised in doing it. The mechanical efficiency of a steam engine may be from 5 per cent. to 20 per cent.: of a gas engine it may be higher, say up to 30 per cent. In man, the mechanical efficiency of muscular movement may be as high as 25 per cent.; the remaining 75 per cent. loss of energy is a serious thing: to what is it due? It seemed, from the purely physico-chemical point of view, that an efficiency of 100 per cent. was conceivable: the free energy of the oxidation of food-stuffs is very large. We know, however, that the body has been organised so that it can go on for a while without sufficient oxygen; it is like an accumulator: it can be discharged and then recharged: it can run into debt for oxygen, and pay off its debt afterwards.

If an animal like man were forced to live within his "oxygen-income," and were able only to make efforts which were possible on his contemporary oxygen supply, he would be a very feeble creature: only about $\frac{1}{8}$th as energetic (for short-lived effort) as he actually is. Moreover, oxidation in the body is a very slow thing; it takes minutes to complete, and it would be a disadvantage to take three minutes over every muscular movement. Hence the mechanism of the muscle has been evolved and differentiated on a different plan: oxidation is not the chemical reaction which directly and immediately provides the mechanical energy of the muscle: the actual process which produces the mechanical energy appears to be some kind of explosive transformation of a glucose di-phosphoric ester into lactic acid, and the subsequent physical or physico-chemical reaction of this lactic acid with the protein structures of the muscle. In recovery the lactic acid is restored, about $\frac{5}{6}$th of it, to the precursor from which it came, the remaining $\frac{1}{6}$th (or its equivalent amount of glycogen) being oxidised to provide the energy for the reversal. Mechanical energy is liberated only in the first stage, which appears to have a very high "efficiency"—probably about 100 per cent. In the recovery stage, however, 150 units of heat are liberated by oxidation for every 100 units in the initial stage, and this reduces the efficiency of the whole cycle to about 100/250, *i.e.* to about 40 per cent. Apparently, therefore, a big reduction in efficiency is effected simply by taking proper account of the recovery process, and is due to the need the animal often experiences of taking violent exercise, so to speak, "on credit."

Even so, however, 40 per cent is far higher than the efficiency actually found in man: the remaining reduction of efficiency is due to two other factors: (*a*) to the rapidity of the usual type of muscular movement, and to consequent frictional loss inside the muscle; and (*b*) to the physiological effort associated with *maintaining* a contraction.

With regard to (*a*), muscle is made up of a viscous material, not unlike egg-white or treacle, with a fine network of membranes, fibres, and tubes throughout it: the joints, the tendons, the connective tissue, the blood-vessels and the blood within them, are similarly of a viscous nature. Now, when a viscous fluid is forced to flow, mechanical energy is wasted and turned into heat: the faster it is made to flow, the more energy is degraded. But when a muscle changes its form, and produces a movement in a limb, the tissues have all to fall into a new form, viscous fluid has to flow into a new disposition, energy is degraded into heat: and in the more rapid movement we should expect more energy to be wasted. Experiment amply confirms this expectation: the frictional loss is greater, the greater be the speed of movement. This explains why it is so laborious to pedal a bicycle on too low a gear, and why very rapid running requires such an enormous amount of energy. In both cases the external resistance may be small or negligible. The internal resistance, however, is large, and increases directly as the speed of movement, until finally a limit is reached at which no further increase in speed is possible; every muscle fibre is then working to its physiological limit of speed and power, merely in overcoming its own internal resistance.

With regard to (*b*), just as it is inefficient and tiring to move our limbs too rapidly, or on too low a gear, so also it is inefficient and tiring to move them too slowly, or on too high a gear. This simple observation gives us the clue to the third and final reason why the efficiency of muscular contraction is relatively so low; a contraction which continues too long requires energy to maintain it, as well as energy to set it up, and from the point of view of doing external work the *maintenance* of contraction is ineffective. Experiments were made in which the heat produced by a muscle was determined as a function of the duration of the stimulus exciting its contraction. After an initial outburst of energy associated with setting up the contraction, the heat-production increases uniformly as the duration of the stimulus is increased. Hence we see why slow and prolonged movements are inefficient: a large and unnecessary part of the energy is used in maintaining the contraction. This is the phenomenon we all know in our own bodies: to attempt to lift a thing which is too heavy for us to move is more tiring than actually to lift a thing we can move, even though no work at all—in the mechanical sense—be done in the former case.

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Supplement to NATURE

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The Ether and Electrons.[1]

By Sir OLIVER LODGE, F.R.S.

PRELIMINARY.

I HAVE been asked to speak on possibilities of research in pure physics, and I rejoice that attention has always been paid to the vital importance of pure science in an Institution the backbone of the work of which must be of a metrical character connected with industrial applications, and much of it necessarily subject to routine.

The main lines on which physics has recently and is still so rapidly advancing are well known. There is no need to direct attention to such inquiries as are the direct outcome of radioactivity, in its various forms spontaneous and induced: problems which range from atomic investigations like those which go on in the Cavendish Laboratory, through X-ray and ordinary spectrum analysis, down to the various devices of wireless telegraphy. In all these things there are among the members of the staff of the National Physical Laboratory, and on the Governing Body, more than competent advisers.

I must just deal with such ideas as have been occupying my attention of late. I have found it interesting recently to look up some forgotten remarks of my own—made soon after a National Physical Laboratory was decided on, but before it was founded—in the preliminary portion of a presidential address to the Physical Society of London on February 10, 1899, as reported in the Proceedings of that Society, vol. xvi. Part VI., June 1899. Among other things there referred to, is a suggestion by FitzGerald that circularly polarised light sent through an absorbing medium might constitute it a magnet—a discovery not yet made. I see there also a reference to a Blue-book of 1898 recording a Government conference about the founding of this Laboratory. Sir Richard Glazebrook has also kindly directed your attention to my address to Section A of the British Association at Cardiff in 1891, in which the foundation of a National Physical Laboratory was specially advocated.

[1] From an address on "Some Possibilities for Research in Pure Physics, especially on the Ether," delivered to the staff of the National Physical Laboratory on March 14. The first section of the lecture is omitted for lack of space. It dealt with possible research in boundary or overlapping regions of specific sciences, and on the relation between physics on one hand, and chemistry, physiology, and biology on the other. This section, and one giving further details about the possibility of a renewed attempt to detect or to disprove an ether flow along lines of magnetic force, will be published elsewhere.

PROPERTIES OF THE ETHER.

The question of what constitutes a distinction between physics and chemistry is difficult to decide, but in general it may be said that chemists deal chiefly with static relations and groupings, while physicists are more inclined to treat phenomena kinetically. Another clear distinction, at any rate at present, between these two sciences is that one deals with matter only, and the other deals with the ether also. It seems that the electric charge is the unifying or connecting entity between matter and ether. Uncharged matter appears to have no effect on ether at all. But its charged particles, or electrons, in so far as they quiver or rotate, do disturb the ether and generate waves in it. Moreover, if they revolve or travel, as by locomotion, they generate magnetism in it; and even when they are stationary, they generate in it or rather are inevitably accompanied by what is called electric force. That is, they appear to attract or repel each other from a distance. Furthermore, for some reason—which I and some others think to be residual electric or possibly magnetic attraction,—they exert over minute ranges the force known as cohesion, which again must be exerted entirely through the ether, since particles of cohering matter are not in contact. And again they exert, even at the most enormous distances known to astronomy, the minute residual force known as gravitation; which in the case of bodies of astronomical size amounts to a force of gigantic magnitude.

Light, magnetism, cohesion, gravitation,—all these are affairs of the ether, and are all studied in physics. A superstition has recently arisen that the ether is an exploded heresy, and is unnecessary; but that is an absurd misunderstanding. The theory of relativity says nothing of the kind. As a mathematical method it need not mention the ether, any more than Laplace in his "System of the World" felt that he need mention the Creator. He was entirely within his rights in ignoring the Deity; and so is a relativist in ignoring the ether; at least when neither attempts to philosophise on that basis. For ignoring a thing is not the same as putting it out of existence. Extinction is as impossible to us as Creation. We have to take things as we find them: and we find ourselves imbedded in ether and matter. So we had better make the best of it.

PRESENT KNOWLEDGE ABOUT ETHER.

How much do we know about the ether, and how much is it possible to ascertain? We do not know as much as we ought, but we know a few things; and we hope by further investigation to know more.

Unfortunately, the ether is a very perfect, elusive, highly-endowed substance, which makes no direct appeal to any of our sense organs. Accordingly, it is only investigated with some difficulty; and its properties are so different from those of matter that very elaborate and expensive arrangements have to be made in order to cope with it. Even when we have made those arrangements, it may decline to give an answer, and the result may be negative. Still, a truly negative result is something definite, and is better than nothing. But every positive result is of extreme value. Let us summarise the results we already know.

First of all, we know that the ether can transmit waves at a definite and finite speed of 300,000 kilometres a second. Next, that those waves are electromagnetic, with the electric and magnetic vectors at right angles to each other, and in the same phase. We also know that the superposition of related electric and magnetic vectors in the same phase results in propagation with the speed of light.

Then we know that light cannot be transmitted by conductors of electricity, which act like a solution of optical continuity. Furthermore, inside a transparent body light travels more slowly than in free space, showing that the ether is affected somehow by the neighbourhood of matter; the amount of this affection being sometimes called the refractive index, which is the measure of the retardation experienced by light, and sometimes, from another point of view, the dielectric coefficient.

We further know that if transparent matter is moved in the direction of the light inside it, a certain fraction of its velocity is added to the light—added of course algebraically. Thus demonstrating, not that matter has any power of conveying light—which it has not—but that some influence or reaction on the ether belongs to the matter and travels with it; that influence being just the one which effected the retardation and is responsible for the refractive index, the fraction of added velocity being, as surmised by Fresnel, $1 - 1/\mu^2$.

We also know, from certain experiments conducted by myself, that this property of matter does not extend in the slightest degree beyond its boundary; so that however fast matter is moving, light just outside it is not affected at all. Or, as we may express it, matter has no power of carrying the ether with it. The ether has nothing of the nature of viscosity. If a fluid at all, it is a perfect fluid. Not even if the matter is charged or magnetised does the influence extend beyond its boundary so as to affect the stream of light close to it. (See *Phil. Trans.* 1893 and 1897.)

Yet inside transparent matter the phenomena of light show that the ether must be modified in many ways, giving rise to all manner of crystalline effects —the optics of crystals—and the various phenomena of polarisation; especially that interesting one discovered by Faraday, that the plane of vibration is rotated, in one direction or another, by even non-crystalline and fluid matter when immersed in a longitudinal magnetic field: and those other phenomena discovered by Kerr, all of which may be summed up under the names elliptic and rotatory polarisation.

It is easy enough to say that light is retarded to a definite extent by transparent matter, but the complete theory of it is not so simple. Something about it will be found in the writings of Sir J. J. Thomson. All the phenomena of dispersion and anomalous dispersion must be taken into account if we would understand the inter-relation between matter and ether.

New Effects.

Not long ago the interesting phenomenon was discovered by Prof. Richardson that the act of magnetisation rotates a piece of iron, and a quantitative investigation of this delicate effect has been made recently by Prof. Chattock and Mr. Bates. I understand that a converse effect has now also been observed by Mr. Barnett, namely, that rotating a piece of iron magnetises it. I remember making an attempt to discover such a phenomenon long ago at University College, London; but I found nothing securely. Capricious and spurious effects were difficult to avoid, and I suppose I had not sufficient perseverance. We knew nothing in those days about electrons or their orbits, though we felt that there was something rotatory about magnetism; nor was it more than a suspicion that electricity itself might possess a trace of inertia, in addition to the recognised quasi-inertia of self-induction. Modern skill may have been able to overcome the difficulties inherent to such an experiment, but caution is desirable, since it is not clear why rotation should develop one polarity rather than another, if the atomic arrangement were truly random.

There is more to be got out of the original discovery by Richardson than has yet appeared—and I venture to predict that we have by no means heard the last of it. The Zeeman effect seemed small at one time; and if it be said that the Richardson effect could have been anticipated, I reply that Larmor anticipated the Zeeman effect; though it is true he did not expect the right magnitude, because the mass of the particle responsible for radiation was not then known. The quantitative relations of the Zeeman phenomenon clearly showed, for the first time, that the radiating particle was one of electronic and not of atomic mass.

I mention these two apparently disconnected phenomena together advisedly; for while the orientation or precession of electronic orbits in gases account for the Zeeman effect, the orientation of electronic orbits in iron accounts for the Richardson effect. Both are small, but the Zeeman effect is the smaller of the two; it needs the appliances of spectrum analysis for its detection. It is far bigger than it would have been if the atom had been the radiating element instead of the thousand-times smaller mass of the electron. As to the Richardson effect, it is surprising that it has been observed and measured at all, for the smallness (in mass) of the electron is no help to that; and the detected reaction is not something optical or etherial, but the gross movement of a mass of ordinary matter. Not much movement, truly,—quartz fibres must be used of course, and plenty of refinements,—but still a material movement is observed as the result of orientation of electronic orbits; and that is noteworthy. Reaction of radium from atomic projectiles was observed before, and reaction of radiometer vanes too; but alpha rays are atoms, and these

effects are connected with atomic bombardment; so in that respect they differ from the effects just mentioned.

I would liken the Richardson effect in some respects more to the Lebedew and Nicholls and Hull detection of the pressure of light, as suggesting an etherial reaction on ordinary matter.

Referring to this light-pressure; it is so small that Crookes failed to detect it, just as Faraday failed to detect the Zeeman effect with the appliances of his day and without a Rowland grating; but the most trivial fact, so it be a fact, is of enormous and may be of cosmic importance. Poynting invoked light-pressure to account for cometary and other astronomical results; and now Eddington calls upon it to sustain the Atlas-like burden of holding up the billions of tons of superincumbent material which constitutes the crust or envelope of a giant star. An amazing application of the (terrestrially) almost infinitely small.

Parenthetically, in using the term so-and-so's "effect," I do so under protest. This personal kind of nomenclature should be temporary, and not outlive the generation of discovery. This kind of naming began with either the Doppler or the Peltier effect, and was right enough when novel effects were few; but now that they constitute a multitude, we older folk are apt to get confused among the plentiful crop which the more fortunate youngsters are continually evolving. Prof. Richardson is entirely free from blame, for he calls his discovery a gyro-magnetic effect; which is explicit and satisfactory.

The Positive Electron.

Before leaving this part of the subject I should like just to direct attention to what I have written in NATURE for November 25, 1922, p. 696, that we have not yet securely discovered the positive electron. The proton has to serve that function for the present, but what the constitution of the simplest known nucleus of an atom is, remains to be determined. Something is known about the proximate or apparent constituents of some heavier atomic nuclei, though not much, but nothing at all of the constituents of the nucleus of a hydrogen atom. It *may* be an indivisible particle so small and concentrated as to have a mass 1800 times that of a negative electron; but to me it seems unlikely that this is the right solution. It *may*, on the other hand, be built up of a stable grouping of hypothetical electrons both positive and negative,—each one being like a mirror image of the other. If so, it remains to be explained why the outstanding charge of all atomic nuclei is apparently positive, and whether that is accurately true. All I advocate is to keep the door open for further investigation, and to persevere with the quest of the positive electron by any methods that may suggest themselves.

Why negative electricity should differ from positive so greatly, or in any respect save in sign, is not at all clear; and it is difficult to understand how one of these entities can have been constructed out of the ether, without the simultaneous production of its opposite partner.

Electrical Theory of Matter.

The mechanics of the ether are not yet known; and until we have devised some system of mechanics which applies, not in a blindfold, but in a clear and lucid, manner to the behaviour of the ether, we must remain to some extent in the dark. Here, then, is scope for experiment. At present we are using ether waves to examine the properties of matter, the structure of crystals, the structure of molecules, and even the structure of the atom. But we must go on in due time to use these phenomena for an investigation of the ether itself. We know that movement of matter does not affect the refractive index nor the polarising properties of that matter. But we know that if matter is moving fast enough, it tends to carry some ether with it, and thereby adds to its own inertia to a known and predicted extent. We also know that inertia itself is a magnetic and therefore etherial phenomenon. The way in which J. J. Thomson, Heaviside, and Larmor have worked out the electrical relations between ether and matter, as regards inertia, changes of inertia with speed, and radiation consequent on acceleration, has been a marvellous achievement of our time, of which quite inadequate popular notice has been taken. Still there it is. They have laid the foundation of the Electrical Theory of Matter, and have opened up a way for our descendants to explain nearly all the properties of matter in terms of the ether, and possibly the very existence of matter itself.

We do not yet know how an electron is composed. We know still less—if that is possible—how a proton is composed. But that they ultimately will turn out to be etherial structures of some kind is possible and, as I think, probable.

Meanwhile we know that not only the mass of bodies, but their shape, is affected by motion through the ether; this was demonstrated by that great experiment of Michelson's, which I regard primarily as an experiment on matter by means of light, and not an experiment on light by means of matter. It may hereafter be regarded by a sensible though preposterous historian—that is, one who puts the cart before the horse—as the first and only verification of the Fitz-Gerald-Lorentz theory of modified electrical cohesion, or peculiar interaction between moving particles. It has been used as the foundation of the Theory of Relativity. But that is an ingenious offshoot or excrescence. I should like everybody to realise that the Electrical Theory of Matter had already accounted for nearly all the things which drop out so naturally from the theory of relativity: such as the increase in mass, the FitzGerald contraction as a reality, the Fizeau effect on light; even an extra revolution of the axes of a planetary orbit, unless gravitation itself is modified by motion. (See several Articles in the *Phil. Mag.* between August 1917 and June 1918, by Prof. Eddington, G. W. Walker, and myself; beginning with page 81 of vol. 34, and with conclusions summarised on pp. 143, 482, and 486 of vol. 35.) The Electrical Theory of Matter may conceivably be made to account for the two other as yet incompletely verified gravitational effects so brilliantly predicted by Einstein. But that remains to be seen.

Possible Experiments.

Limits of space will not permit me to deal here with the possibility of an experiment to determine whether there really is etherial circulation along magnetic

lines of force; attention may be directed, however, to papers describing my early attempts at such experiments, as partly described in the *Philosophical Magazine* for April 1907 and May 1919. In making experiments on the ether we must recognise that what we set out to look for we may not find: but we can also remember that careful and conscientious experiment, conducted with good apparatus, must lead us somewhere, and may result in a discovery exceeding in importance and interest any property we had set out to examine.

Kinetic Elasticity.

The contrast between the kinetic and the static mode of regarding things runs all through physics. Most physicists are imbued with the more fundamental character of a kinetic explanation, and never feel really satisfied with an explanation in terms of static or potential energy. Of the two kinds of energy, kinetic appears to them the more fundamental kind.

So, as we all know, Lord Kelvin tried to explain the elasticity of a spring balance, or any spiral spring, by means of gyrostats, or spinning tops. He was able to devise, at any rate theoretically, two concealed mechanisms, one of which was static and the other kinetic; that is to say, one of which contained a spiral spring with a protruding hook at the end, while the other contained a precessing system of gyrostats, also with a protruding hook. The observer was challenged to hang things on the hook, or to feel its recoil, and to say which was which. Or, in more general terms, Lord Kelvin endeavoured to devise a kinetic theory of elasticity. His famous theory of the vortex atom, in which he tried to explain some of the properties of atoms in terms of vortex rings and their collisions and interactions, was of this nature. It was extended by J. J. Thomson at an early date into almost chemical regions, in his early Adams' prize essay.

In his later life, Lord Kelvin was inclined to abandon this view of elasticity as regards solids; and his vortex atom declined to satisfy either him or others, on further development. But none of these ideas should be completely abandoned. In so far as they successfully illustrated any of the properties of matter, they are worthy of consideration. Although we now know that the atom is not a vortex ring, or anything like it, I would challenge any one to say the same of an electron. The electron has become the fundamental material unit: and what its constitution may be, we none of us know. It must be in close relation with the ether, and must ultimately, as I think, be explicable in terms of the ether. But the fundamental properties of the ether are too little known at present to enable this to be done. We cannot say whether the electron is to be explained statically as a knot or other geometrical configuration or strain centre, on one hand, or as some kind of circulating or vortex movement on the other. The constitution of the electron remains for discovery, in spite of all the work of Larmor on the subject in his brilliant book "Ether and Matter," and other papers imbedded in the *Phil. Trans.* If it should turn out that an electron can be thought of as a knot or any kind of static strain, then I for one feel that that cannot be regarded as an ultimate explanation, though a most useful approximate one, and that the strain will have to be resolved into or accounted for by some kind of etherial vortex motion.

Not only have the electric and magnetic forces belonging to an electron, respectively at rest and in motion, to be explained; but also the slight residual strain depending on the square of the charge, and therefore irrespective of sign, which we call gravitation, has in a complete theory to be explained also. For few can doubt, I think, that gravitation must now be regarded as a function of the electron and the proton, that it is not something which springs into being when these units are associated so as to constitute an atom of matter; it is unlikely that the tight packing of a large number of hypothetical positive and negative units in the proton could account for it. More likely gravitation will turn out to be an etherial phenomenon explicable in terms of the beknottedness which distinguishes the singular point of an electron from the rest of the ether. The rest of the ether is not affected by gravity, but possesses qualities akin to what in mechanics we call elasticity and inertia. Otherwise the unspecialised ether of space could not transmit radiation, or sustain a magnetic field—as we know it does. For it is necessary always to remember that though electric lines of force terminate on material units, most of their course lies in undisturbed ether: while magnetic lines of force do not terminate at all, but are always closed curves, surrounding electrons in motion, but themselves existing, I presume, wholly in the ether, and showing every sign of being essentially a kinetic phenomenon, demonstrative of inertia.

Inertia itself I see no way of explaining in any fundamental manner. It seems to be a property that we must postulate as existing in the ether,—a property akin to density; though it is true we can explain the inertia of matter—that is, of any material unit—in terms of the concealed magnetic fields inevitably associated with its motion.

To leave these more transcendental regions for the present, we may recall that although the kinetic theory of elasticity has hitherto failed to develop in connexion with solids, it holds perfectly for the case of gases. The elasticity or recoil of compressed air used to be thought of as analogous to the recoil of an elastic spring. But Waterston first, and then Joule and others—including especially Maxwell and Clausius and Loschmidt,—explained it brilliantly, together with many other of the metrical properties of gases, as the result of molecular motions and bombardment; so that it has become a familiar and elaborate theory—the Kinetic Theory of Gases. Hence, in that form of matter about which we know most, the kinetic theory of elasticity holds the field.

Radiation and Matter.

Now come a series of questions which it is difficult to formulate precisely because of our inadequate knowledge, and concerning which we must make the best of the hints which from time to time are afforded us by Nature,—questions which are mainly concerned with the nature of radiation, and with the interactions between ether waves and ordinary matter.

It is unnecessary to point out in the first instance that light is now known to exert pressure, and therefore to convey momentum. An advancing wave-front possesses momentum, which it can transmit to any obstacle which either reflects or absorbs it. If reflected, the pressure it exerts is double what it exerts when absorbed; all quite in accordance with common sense. But I rather want to concentrate attention on the state of things when the wave-front is advancing—it may be for hundreds of years—through so-called empty space. It carries with it a pressure equal to the energy per unit volume. If the Third Law of Motion is true without exception,—and it is surely politic to assume the truth of that law until it is negatived,—there must be a longitudinal stress in that stream of light, with a reaction on the source at one end and on the advancing wave-front on the other.

The source is always something material. Light can only emanate from an accelerated—that is, from a revolving or vibrating—electron. Hence, at that end the reaction has a material basis, in accordance with the customary experience that a line of stress must stretch from one piece of matter to another. But what happens at the other end? When it encounters matter, the reaction is exerted on that matter, and everything is plain sailing. But while it is advancing in free ether, what is it that sustains the reaction? We can only answer, the wave-front. The wave-front cannot sustain it statically. It can only do so by advancing at the speed of light. But it is remarkable and worthy of note that in this particular the advancing wave-front simulates one of the properties of matter, namely, the power of sustaining stress.

Now to me this is very suggestive. We do not know what precisely is the kind of motion occurring in the associated electric and magnetic vectors which are travelling with the speed of light. We do not know the kind of motion associated, more statically, with an electron. But the guess is almost forced upon us that possibly these two kinds of motion are not entirely distinct. We could not say that perhaps they are one, and not two; for there are certainly differences between them. One must advance; the other may stay still. But is it possible to regard one as a consequence, or as a generator, of the other?

The electron generates light.

Does light generate an electron?

(I am using the term "Light" in a very general sense, not limiting it to the physiological kind which excites the sense of vision, but including X-rays, and all other forms of short wave radiation.)

What do we know about the effect of this kind of radiation upon matter? We know that it can produce the irregular movements that we call heat, and also that it can stimulate chemical action. But the discovery of photoelectricity shows us that it may do more. It may fling out an electron, with a surprising amount of energy, dependent upon the frequency, that is, upon the wave-length, of the incident radiation. This is a hint not to be ignored. Nor is it ignored; and there must have been many speculations as to the kind of way in which it achieves this result. One would naturally suppose at first that it must do it by means of resonance, that is, by the accumulation of properly timed impulses, until an explosion occurs. But the evidence is, on the whole, rather against a resonance view; because the result seems almost independent of the intensity of the incident radiation, and to depend only on its wave-length. Nor does it seem as if a great length of radiation was necessary in order to produce the result: though this is a matter which requires further and more conclusive experiment. If a beam of light is interrupted and cut up into small sections—as might be done by a narrow slit in a very rapidly revolving disc,—would this intermittent light be equally effective? For if it is equally effective, the fact would tend against the continuous accumulation of a small synchronous disturbance.

I believe that some experiments have been made in this direction, and that the answer—so far as it goes—is that intermittent is as effective as continuous illumination, and feeble light as efficient as strong. The energy falling upon a minute surface in a beam of diffuse light is insufficient to account for the energy of the resulting effect, unless it is a trigger effect.

But this rather wants pressing to extremes. To cut up a beam of light into really short portions is not very easy. If a radial slit a millimetre in width is made in a disc a metre in diameter, revolving a hundred times a second, light sent through it is diluted and cut up into sections; but the length of each section is still about a mile, and accordingly would contain more than a thousand million waves,—which is amply sufficient for resonance.

However, the evidence so far is supposed to negative the resonance idea: so much so that it has been supposed that the wave-front is not a uniform surface, but a speckled one; that it is discontinuous; and that the amount of energy concentrated in one of the specks may be vastly greater than would be reckoned on the diffuse or continuous theory.

The idea of a speckled wave-front would have seemed to our scientific ancestors rather wild; though it must be remembered that Newton, with his Corpuscular Theory, was temporarily satisfied with something very like it. Nevertheless, the Corpuscular Theory had to be abandoned because of the artificial way in which it explained polarisation, and because it seemed to require that light should travel quicker inside matter than outside, instead of slower—as Foucault proved it to do,—and because there are real difficulties in explaining interference and diffraction, unless the wave-front is continuous.

However, it does not do to turn down a theory too readily and prematurely, merely because we encounter a few difficulties. No hypothesis is wild which has attracted the serious attention of J. J. Thomson, and other brilliant physicists, including—as I think we must—even Faraday; as evidenced by his "Thoughts on Ray Vibrations" ("Experimental Researches," vol. iii. p. 447).

Moreover, though these ideas, as we perceive them at present, may not be able to substantiate themselves, yet they are the outcome of observed facts; and it may yet be found that, in a modified and revolutionised form, they may contain elements of truth at present unsuspected.

Wilberforce Model.

It may be said that if we depend on the pressure of light as conveying energy, it is a longitudinal phenomenon; whereas an electron is probably a rotatory or rotational phenomenon. Or again, if we attend to the magnetic oscillation in the beam of light, and consider that the electric oscillation is separated from it, or neutralised, by matter, that still there is nothing of the rotational kind about it.

One answer would be that circularly polarised light clearly has a rotational aspect. Another and more fundamental answer would direct attention to the transition, or interchange, that may go on between a linear oscillator and a rotational oscillator when they are of the same frequency, or properly attuned.

In illustration of that, I would invite attention to the illustrative models constructed by Prof. Wilberforce, my successor in the chair of physics at Liverpool, which show that a continual interchange of energy between a linear vibration in one direction, and a rotational vibration in a plane at right angles, naturally goes on when the two modes are synchronous. Thus the energy alternately takes first one form and then the other; and then back again, without intermission.

Of course the dynamics of the model is thoroughly understood, and Wilberforce himself has explained it, that is, has recorded the relevant equations;[2] and in that sense there is nothing puzzling about it, though its behaviour can be made to look rather paradoxical. But I feel that there is some meaning underlying the possibilities here indicated, which are not yet completely exhausted, and that they may, when more deeply considered, throw some light upon the interaction between electricity and magnetism—if that should still be necessary,—and possibly on the interaction between ether and matter, and perhaps between waves and electrons, where more information is certainly necessary. At any rate, I regard the behaviour of the model as suggestive, and am content for the present to direct attention to it, from this point of view.

Origin of Electrons.

Let us assume, then, for a moment that there may be some truth in the idea of a discontinuous wave-front. To what are we led? I should reply, that the motion in a wave-front seems more akin to the kind of motion that constitutes the discontinuous and isolated speck that we call an electron; and that the actual generation of an electron by means of light is not an altogether impossible idea.

So I repeat the question:

An electron suddenly set in motion generates light: does light when it is suddenly stopped generate an electron?

Sir William Bragg has often directed attention to the singular relation existing between X-rays and beta radiation. The impact of a beta particle emits X-rays. The impact of X-rays emits a beta particle. The energy of the original and the excited beta particle are so closely proportional as to be practically identical. It is as if the same beta particle, that is, the same electron, had gone out of existence at one place, and been recreated at another, the intermediate link being constituted by specific radiation of a perfectly definite wave-length.

There is no need to *assert* that one particle has gone out of existence and the other come in; and yet we know of no reason for denying it. It may have to be denied, but I think it wise to keep an open mind on the subject, however bizarre the notion may be. There are strange relations between energy and matter now coming to the front. Matter contains intrinsic energy, as if it were something circulating with the velocity of light. There must be some meaning in this. The ratio c^2 between matter and energy is not to be ignored.

Somehow or other the ether possesses inertia. It must, or it could not sustain magnetism, or account for the increase of inertia due to motion. The ether also contains an intrinsic and characteristic velocity, which is perfectly definite. It is known that the vibrations of vortices, and the speed at which a vortex medium can transmit transverse waves, are closely connected with the constitutional velocity of rotation. The two velocities are in fact equal, or connected by a numerical factor, of a magnitude which some theories make $\sqrt{2}$, but other theories make unity. In any case the numerical factor is not far from unity. We are justified in supposing that if the ether is full of circulatory motion, that motion must be practically the velocity of light. In that case, the fundamental nature of matter would appear to be giving up its secret; and the relation between matter and energy would be explained.

There does not then seem any insuperable difficulty about hoping that some future discovery will be able to generate matter, or at least to generate an electron, by aid of X-rays or other form of radiation. I can dimly conceive a theory of light which, when its advance was stopped, should terminate not in the irregular jostle called heat, but in the regular circulation or vortex motion that we call an electron. The intimate relation between energy and frequency associated with the quantum seems to me to negative the mere irregularity of thermal agitation, and to suggest something quite regular and constitutional.

We can go further, and can reckon how much matter would be generated by a given amount of luminous energy, if none of it were wasted as heat. A beam of ordinary sunlight ten centimetres square shining continuously, and supposed to be all converted or interpreted as matter, would generate a weighable amount, namely one-tenth of a milligram, in seventeen years.

The density of sunlight near the earth is equivalent to 2×10^{-15} gram per second per square centimetre. So if it were interpreted as matter, the earth would catch 80,000 tons of it per annum. Of course, some of it is wasted. Only radiation of the right frequency is effective, just as only energy of the right frequency is generated by a metrical impact. A lot of the radiation may be due to irregular jostling, and this portion when absorbed may result in heat. But it is the more precise kinds of occurrence which are instructive, and which must inevitably attract attention.

I know that the Bohr Theory of the Atom seems at first against these speculations. Electrons appear

[2] *Phil. Mag.*, October 1894.

to jump from one orbit to another, and thereby give out a certain quantum of energy. But this may be a supplementary and not a contradictory statement. What makes the electrons jump? Which electron jumps out? Sometimes it is from the K ring, sometimes from the L ring; and so on. All those things may be known. But still I ask, What started the disturbance? If an electron is generated by the impact of light, it does not follow that that particular electron is the one ejected. Its entry may be the means of ejecting another. Somehow or other the atom must get another, in order to restore its constitution. There are doubtless many ways in which a strayed electron could be recaptured; and I venture to suggest that our speculation suggests one of them.

Possible Utilisation of Waste Radiation.

There is an immense amount of radiation travelling about space. The whole amount of solar radiation is portentous. The fraction which the earth catches, though terrestrially so important, is but a minute fraction of the whole—less than the two thousand millionth part,—and it seems to have been going on for hundreds of millions of years. The radiation from many of the stars is greater. What becomes of all that radiation? Is it all waste? Space is so enormous that though thousands of millions of suns have been pouring out their energy for thousands of millions of years, space is no warmer. The ether is not warmed by it: the ether does not absorb it. The ether is perfectly transparent. Yet our instinct rebels against the idea that all this radiation results in nothing. Sir W. Siemens speculated as to its possible concentration by total reflection at an ether boundary. But I cannot imagine an ether boundary. I can more readily imagine that light results somehow in the generation of matter; and that there is a reciprocal interaction between matter and ether waves; so that each is generated by the other,—a sort of constant and perennial interchange.

Electrons have come into existence somehow. The subject of origins usually lies outside science. The origin of matter is as beyond our ken as the origin of life; and yet people speculate about the origin of life. Some highly estimated men of science *hope* at any rate that some day the chemistry and physics of life may be so far understood that a highly complex assemblage of organic molecules may simulate and perhaps adopt its functions. I see nothing inconceivable in this. Life has originated somehow; and if we can get to understand anything about its origin, the effort is legitimate. It may fail; but it would be a very superficial view of religion which resented its success. Mind dominates matter; and the mind of man is not altogether of a different order from the mind of the Creator. But this is a subject on which I could say more on a more suitable occasion. I only say thus much now in order to repel any idea of impiety in speculating on a possible origin for matter.

Hypothetical Conversion of Radiation.

The possibility that a small body may gradually grow in mass under the influence of an etherial transformation, does not seem one to be scouted without proper examination. The amount of matter scattered about in space is by no means inconsiderable, and the problem of its origin has never been attacked. Given matter, the origin of radiation has been more or less solved. But, given radiation, the idea of its conversion into matter has not, so far as I know, been mooted. Possibly the idea is erroneous. But interactions in Nature are so frequent, and the interrelations between ether and matter are so ill understood, that I think we should not shut our eyes to the possibilities of some reciprocal interaction, even of a generative kind.[3]

Sometimes I see the difficulties of the hypothesis; sometimes I feel impressed with a sort of probability about it. It is easier to see the difficulties than the probabilities. But the relationship between energy and matter—connected as they appear to be with the second power of the characteristic ether velocity, and with the conception of an intimate fine-grained rotational structure for the ether—is not a hint that should be too lightly ignored or neglected.

Electrons build up matter. What builds up electrons? They are somehow intimately connected with the ether; their motion through it displays to us the phenomenon of magnetism; and their acceleration generates waves. So far, we are on firm ground. When we come to the converse or reciprocal relations, we have but few facts to stand on. But the emission of electrons by means of light is one of them; and the bearing of this fact, until it is properly understood inevitably justifies speculation.

Previous Guesses.

When I say that the idea of reciprocal conversion has not been mooted, I am going beyond the facts. In Loring's "Atomic Theories," page 80, I find the following sentences:

"Thus it would seem that the energy phenomena are reversible, so that the radiation is as it were convertible into moving electrons and moving electrons are convertible into radiation. It is of course only the energy which is thus convertible. The mechanism of conversion is not, however, known."

Again, in Millikan's book "The Electron," when speaking of Barkla's discovery of the remarkable absorbing property of matter for X-rays, he says:

"It will be seen from these photographs that the atoms of each particular substance transmit the general X-radiation up to a certain critical frequency, and then absorb all radiations of higher frequency than this critical value. The extraordinary significance of this discovery lies in the fact that it indicates that there is a type of absorption which is not due either to resonance or to free electrons. But these are the only types of absorption which are recognised in the structure of modern optics. We have as yet no way of conceiving this new type of absorption in terms of a mechanical model."

Sir William Bragg, in NATURE (1921), vol. 107, p. 79, with reference to the experiments of Duane and Hunt, says: "Exactly how this strange transfer of energy from one form to another takes place we do not know: the question is full of puzzles." He has several times urged the extraordinary character of the fact that a stream of radiation excited by the

[3] Cf. letter in NATURE, May 26, 1923, p. 702.

impact of one electron, after travelling a long way and becoming greatly enfeebled, can eject another electron with the same or nearly the same energy as the first. Facts such as these have suggested the discontinuous nature of a wave-front, and the actual concrete existence of discrete tubes of force, which are apparently analogous to, or suggestive of, vortex filaments in the ether. Again, there is the fact that the electrostatic potential energy of a charge is similar to what the equivalent mass would possess if it were moving with the speed of light. Also, *à propos* of this, I understand that Sir J. J. Thomson has expressed himself thus:

"When the energy of a system passes from kinetic into potential, there need be no transformation of fundamental energy, but merely the flow of a mass-producing material, with its intrinsic kinetic energy, from one position of space to another, under the guidance of the lines of electric force."

In accordance with a few other physicists, Thomson has been led to postulate a fine-grained structure for the ether, which I think rotational, but which he speaks of as particles. He suggests that mass is made up of identical particles all of the same kind, very small compared even with an electron, moving with the velocity of light, and subject only to a deflecting acceleration, not to any change of energy; the mass and energy of each particle being constant, but their distribution depending on the number or concentration of lines of force, each line being as it were anchored normally to positive and negative electrons, but capable of being thrown by motion into loops or closed curves, which would then move away with the velocity of light and constitute radiation. Wherefore it would follow that emission of radiant energy must be accompanied by a diminution in the mass of the radiating body.

The converse, therefore, that absorption of radiant energy might be accompanied by an increase in mass, almost naturally follows.

My presidential address to the Physical Society of London on the subject of opacity, that is, on the orthodox theory of absorption generally,—electrical as well as optical,—is contained in the *Phil. Mag.* for April 1899, and also in the Society's Proceedings; in the latter place it is preceded by preliminary matter not irrelevant to the present discussion.

Mechanism of Absorption and Emission.

To understand the mechanics of absorption we can learn from the mechanics of emission. In a wave the electric and magnetic vectors are simultaneous; that is, the electric and magnetic displacements exist together, superposed. At a source they are only coexistent in space, not in time; one succeeds and gives rise to the other, with successive alternations. A source may be at rest, and is merely an alternator: a wave is necessarily in motion. The relative phases of electric and magnetic oscillations in the neighbourhood of a source determine the fact and the direction of motion at each locality. Combined in one phase they expand or advance, combined in another phase they contract or recede; all this is known to occur near the source, that is, near a Hertz vibrator. In that region, within a radius of $\lambda/2\sqrt{\pi}$, the etherial disturbance oscillates to and fro; and beyond that range a portion of the energy acquires its locomotive character, and sets out with the velocity of light.

Shall not the converse take place when this speed of propagation is annihilated, and the ether disturbance is reduced to locomotive rest, within a similar range near an absorber? In that region the simultaneous electric and magnetic disturbances would be separated, and converted into a stationary oscillation, by a process inverse to that of radiative emission.

Considerations of this character are indicated by me more quantitatively in the *Phil. Mag.* for June 1913, pp. 770-788, and in February 1920, p. 173; also in April 1921, pp. 555-557, where I endeavour to associate the ultimate fate of radiation with a kind of Einsteinian gravitational theory. It there turns out to be necessary to examine electrically the essential nature of absorption; and the illustration or analogy with a Hertz vibrator, as either source or sink, is employed. I return to the subject in June 1921, p. 943, and again in July 1921, pp. 181-183; though in the last paper the chief point is the disintegration of atoms which is to be expected at a certain calculated very high temperature—such as has since been considered by Prof. Eddington likely to occur in the interior of giant stars.

Eddington has taught us—at any rate hypothetically—that in the interior of giant stars, where the temperature is excessive and the radiation powerful beyond easy imagination, the substance of the star is distended, blown out, supported, as it were, by radiation bombardment, as the skin of a football, or an india-rubber tyre, is distended by the molecular bombardment of the air inside. He has further speculated, so I understand, that the interior of these stars may constitute a laboratory in which the more complex atoms can be built up,—those same heavy atoms of which we have now at length begun to witness the breaking down, under the operations of spontaneous radio-activity. There cannot be breaking down everywhere: there must be building up somewhere. We do not yet know what can be accomplished under conditions of extreme heat and pressure,—nor, I may add, under conditions of great pressure combined with extreme cold.

It may be said: the analogy fails, since what I am trying to suggest is the generation of electrons, and we nowhere know of the breaking down of electrons. That is true: we do not know either of their breaking down or their building up. It may be that we shall discover the untying of an electron first; or it may be that we shall discover a tying-up first, and the untying later. Or it may be that, once tied, they are permanent. Or of course it may be that they cannot be tied. But these questions seem to me all open. The time for discovery is not yet; but he would be rash who would say that discovery in any particular region is impossible. If there are any clues, it is the privilege and indeed the duty of science to follow them up. If the clues are imaginary and useless, then open discussion will demonstrate their futility. But if we can see any distance, however dimly, into the unknown, then sooner or later we may be sure that pioneers will explore those dim regions until they are illuminated with the searchlights of systematic knowledge.

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The Adaptational Machinery concerned in the Evolution of Man's Body.[1]

By Prof. Sir ARTHUR KEITH, F.R.S.

INTRODUCTORY.

TELEOLOGY, a word so familiar to readers of the works of Archdeacon Paley and of Sir Charles Bell, has disappeared from the vocabulary of scientific men. Darwin killed it; he put an end to natural theology and to Bridgewater treatises. Yet all those wonderful contrivances which Paley culled from the animal kingdom remain true; they are facts which have to be explained. The human hand is, as Bell maintained, a most effectively designed structure;[2] a modern evolutionist can still study with profit the account he gave of the mechanical contrivances to be seen in every part of the human body.[3] Modern discovery has served but to heighten our sense of wonder at the ingenuity which Nature has lavished on the human body. The means she has installed for fighting infection and internal disorders are almost beyond belief. In complexity and in efficiency of design the human brain far excels any invention or organisation the most fertile imagination of man has yet conceived. Engineers, in designing all their contrivances, ensure stability during emergencies by allowing a "factor of safety"; in all systems of the human body the "factor of safety" is more than ample. In this respect the human body has been made almost "fool-proof."

If, then, teleology has disappeared from our evolutionary vocabulary, its substance remains; we have still to find a rational explanation for the manifest contrivances of the human body; a "doctrine of adaptation to purpose" is still a necessity. The followers of Paley had an easy task; they had but to wave a theological wand, and the origin of all of Nature's contrivances was instantly explained. But we followers of Charles Darwin have a much more laborious undertaking in front of us; we have to discover and demonstrate in the body of man, in the developing embryo, and in the growing child the actual machinery which has wrought its marvellous and purposive organisation. In this lecture, given in memory of Huxley at his old hospital and school, I propose to see how far modern discovery has revealed the nature of the adaptational machinery of man's body.

[1] The 12th Huxley Memorial Lecture, delivered at Charing Cross Hospital Medical School on June 27.

[2] The Hand, its Mechanism and Vital Endowments as evincing Design, London, 1833.

[3] Illustrations of Paley's "Natural Theology." An Appendix to Lord Brougham's edition.

HUXLEY AS HUMAN ANATOMIST.

Of all the men who stood round Darwin as helpful critics, Huxley has come out best; time has upheld his judgments and shown that when he doubted he had the intuition of genius. His opinions concerning the evolution and adaptations of the human body are of particular value, for, at two periods of his career, he was a close student of human anatomy. The first of these was spent in this school, from 1842 to 1846, when he passed from his seventeenth to his twenty-first year, and qualified for the practice of medicine. Then, after sailing the high seas of zoology for a dozen of years, he again made the human body one of his main themes of interest, and it remained so for a period of fully twelve years—from 1858 to 1871—when he again returned to the larger problems of zoology and evolution. No doubt his return to the study of man's body in 1858 was to correct certain doctrines which Owen was promulgating concerning it, and to support Darwin's "Origin of Species," which was issued at the close of 1859.

HUXLEY ON TELEOLOGY.

How, then, did Huxley explain the origin of those excellent contrivances in the human body which had commanded the admiration of so many generations of anatomists? It was not until 1876, when he was in the fifty-first year of his age and at the zenith of his intellectual power, that he gives us a glimpse within his mind and permits us to see how he viewed teleology—the science of adaptation. In the early spring of 1876 he gave a lecture in Glasgow, selecting "the hand" as his subject—the text which had served Sir Charles Bell for a Bridgewater treatise. How had man come by his hand? By what evolutionary means had the clumsy climbing anthropoid hand become the dexterous grasping hand of man? If Huxley had believed, as Lamarck, Spencer, and Darwin did, that "functionally wrought" modifications could become hereditary—that a simian stock, were it to use its arms and hands as man now uses his, would in the course of

many generations come to have human hands and arms—then the evolution of the human hand was a comparatively easy problem. At no time of his life did Huxley believe that the effects of use or disuse did become hereditary. In 1890 he wrote:[4] "I absolutely disbelieve in use-inheritance as the evidence now stands."

Having thus rejected the only known means by which useful or purposive modifications of the body can be brought about, we turn with some degree of curiosity to his lecture in Glasgow[5] on the evolution of the hand. The exact title which he gave to his discourse was "On the Teleology and Morphology of the Hand." This is how he approached the problem of adaptation:

"To be a teleologist and yet accept evolution, it is only necessary *to suppose that the original plan was sketched out—that the purpose was foreshadowed in the molecular arrangements out of which the animals have come.*" Then twelve years later (in a letter to Romanes in 1888) he wrote[6]: "It is quite conceivable that every species tends to produce varieties of a limited number and kind, and that the effect of natural selection is to favour the development of some of these, while it opposes the development of others, *along their predetermined line of modification.*"

Huxley as an Evolutionary Predestinarian.

Thus it will be seen that Huxley, on the evidence then at his disposal, had come to the startling conclusion that the shaping or controlling forces which, in due season, were to give man his hand, lay latent in the germ-plasm of that simian stock which ultimately blossomed into human and anthropoid shapes. The evidence which forced Huxley to take up the position of an evolutionary predestinarian must have been indeed cogent. Only a few years previously (1868), Sir Richard Owen had given utterance to a somewhat similar belief, when he wrote:[7] "Generations do not vary accidentally in any and every direction, but in preordained definite and correlated courses." Huxley, as was afterwards the case with Weissmann, believed that the creative machinery of evolution lay in the womb of the germ-plasm.

Modern Predeterminists.

Manifestly, if the evolutionary fate of man is already determined by the properties of his germ-plasm, as Huxley believed, it is a truth of the utmost consequence to medical men. We cannot, if this be true, in any way control the future of humanity, except by the application of Darwin's law of selection. Man's destiny lies hid in the potentialities of his germ-plasm. Huxley's belief is widely shared by modern students of evolution. No one has had better opportunities of noting how evolution has worked in shaping higher mammals during the Tertiary period than Dr. H. Fairfield Osborn, of the American Museum of Natural History. He finds ample evidence of a "definite or determinate origin of certain new characters, which appear to be *partly* a matter of hereditary disposition."[8] He finds that evolutionary tendencies, like that which leads to the formation of horns and antlers, may lie latent in an ancestral stock, and only become manifest at subsequent times and in different ways in certain of the descendants of that stock. That evolutionary manifestations of this kind have taken place in the evolutionary history of the higher primates—the group to which man belongs—there can be no doubt.

In recent times this conception of evolution working out its effects in predetermined directions has been forcibly suggested by Bateson. In his presidential address to the British Association in Australia in 1914 he expressed himself thus:

"If then we have to dispense, as seems likely, with any addition from without, we must begin seriously to consider whether the course of evolution can at all reasonably be represented as an unpacking of an original complex which contained within itself the whole range of diversity which living things present. . . . At first sight it may seem rank absurdity to suppose that the primordial form or forms of protoplasm could have contained complexity enough to produce the diverse types of life."

In this passage Bateson plainly suggests that the machinery of evolution has proceeded on its way, untrammelled by any outward circumstance, right from the first appearance of living protoplasm. We have here the doctrine of evolutionary predestination stated in its most extreme form. Whether such a belief as this of Bateson is well founded or not, it shows us that one who has given a lifetime to the study of variation and of heredity is of opinion that the evolutionary machinery which has given man his brain, his hand, his foot, and his posture has worked out its effects undisturbed by the surrounding conditions of life. In brief, functionally wrought modifications have had no part in shaping the human body.[9]

Before proceeding to set out the evidence concerning the nature of the machinery which shapes man's body, there is another opinion, akin to that of Huxley, which

[4] Life and Letters, by his son, Leonard Huxley, 1900, vol. 2, p. 268.
[5] Life and Letters, vol. 1, p. 456. I have been unable to obtain any published account of this lecture save that given by Mr. Leonard Huxley in the "Life and Letters."
[6] Life and Letters, vol. 2, p. 188.
[7] Anatomy of Vertebrates, vol. 3, p. 808.
[8] The Origin and Evolution of Life, 1918, p. 278. In this work the reader will find references to literature bearing on predeterminism in evolution.
[9] It is unnecessary to give here a list of the men who have concluded that plants and animals tend to vary in definite directions, whatever be the circumstances in which they are placed. The evidence relating to this matter has been very ably summarised in recent times by E. S. Russell, Form and Function, London, 1916; and by Prof. R. Anthony, "Le Determinisme et l'Adaptation Morphologique," *Archives de Morphologie*, Paris, 1922.

deserves to be considered here. It was given by Prof. G. Elliot Smith,[10] and is founded on a prolonged and intimate study of the brain of man and of the brains of animals which have a close structural relationship to man :

"And if all the factors in his (man's) emergence are not yet known, there is one unquestionable, tangible factor that we can seize hold of and examine—the steady and uniform development of the brain along a well-defined course throughout the Primates right up to man, which must give us the fundamental reason for man's emergence and ascent. . . . Thus at the dawn of the Tertiary period there were developed the germs of all the psychical greatness which, in the million or so of years that have followed, culminated in the human mind."

Without a doubt the brain of the great anthropoids is but an elaborated edition of that which serves the needs of monkeys, and, in turn, the brain of man, while framed on exactly the same plan as that of the great anthropoid, far transcends it in complexity of elaboration. In the evolution of these three stages, represented by the brains of man, anthropoid, and monkey, we are witnessing, not an unpacking, but an ever-increasing degree of specialisation as von Baer and Spencer recognised long ago. In the organisation of the brain of the monkey we see something which is comparable to the civilisation of a primitive people, such as the aborigines of Australia ; in that of the anthropoids, one which may be compared with the life led by a semi-civilised people, such as the natives of the Congo, while in the human brain we reach a stage of complexity represented by the highest modern civilisation. Whether we speak of brains or of civilisation, the machinery of evolution must be of an analogous nature in both of them. What is the nature of this machinery ?

How Adaptations appear during the Development of the Embryo.

Since the time of Darwin and of Huxley our knowledge of the factors which take a part in controlling the development, and therefore the evolution, of the brain and of its appended sense organs, such as the eye, the ear, and the nose, has entered a new phase. We shall take the formation of the eye as our first example because in design and execution it far excels any camera yet invented ; it has been the theme of many a teleological sermon, and a consideration of its development will take us right to the heart of our subject—the origin of purposive or adapted structures. After the publication of the "Origin of Species," Mr. J. J. Murphy, of Belfast, cited the eye as a structure which could not be accounted for by any theory of selection then propounded. "It is probably no exaggeration to suppose," wrote Mr. Murphy,

that in order to improve such an organ as the eye at all, it must be improved in ten different ways at once, and the improbability of any complex organ being produced and brought to perfection in any such way is an improbability of the same kind and degree as that of producing a poem or a mathematical demonstration by throwing letters at random on a table.[11]

Darwin, with that customary candour which regulated his search for truth, quotes in full this cogent and, to my way of thinking, just criticism, and Darwin's reply was that the eyes of men, as of animals, did show slight degrees of individual variation, and that he could conceive the twilight eye of the owl or of the lemur as having arisen by a selection and accumulation of these minute variations. Mr. Murphy modestly estimated the parts of the eye which must undergo a simultaneous modification, if sight was to remain efficient, as ten in number ; he would have been inside the mark if he had said ten thousand. We cannot conceive how the countless elements which go to the construction of an eye can assume their appropriate place, form, and function unless we postulate a machinery which regulates the development and growth of every one of them.

The existence of such a machinery was made evident by experiments on tadpoles carried out by Dr. Warren H. Lewis at Baltimore from 1903 onwards.[12] The optic cup, which ultimately forms the retina of the eye, grows out from the wall of the brain towards the embryonic skin or ectoderm. When this cup comes into contact with the ectoderm, the overlying cells begin to proliferate and arrange themselves so as to form a transparent or crystalline lens. Dr. Lewis transplanted the outgrowing optic cups of tadpoles, and found, if they were placed under the ectoderm of the neck or of the belly, that the result was the same ; an optic cup caused the overlying cutaneous cells to alter their nature and form a lens. Dr. Lewis realised the significance of his discovery ; in the developing embryo, although only of certain species, one group of living cells can enslave and control the behaviour of another group. He gave us a glimpse of the kind of evolutionary machinery employed in fashioning a highly purposive structure such as the eye. Any one who has followed the success with which physicists have unravelled the structure of the atom in recent years will not despair of an equal success attending the efforts of embryologists to uncover the means by which one

[10] British Association Reports, 1912 (Dundee), pp. 575-598.

[11] The Variation of Animals and Plants under Domestication, 1868, vol. 2, p. 222.

[12] "Experiments on the Origin and Differentiation of the Optic Vesicle of Amphibia," *Amer. Jour of Anat.*, 1904, vol. 3, pp. 507, 805 ; 1907, vol. 7, pp. 144, 259. See also Spemann, *Zoolog. Jahrbuch*, 1912, vol. 32, p. 1.

group of embryonic cells regulates the growth of a neighbouring group.

Our knowledge of the machinery by which the growth of embryonic tissues is controlled and shaped is likely to increase rapidly, for in recent years embryologists have copied the methods invented for the study of bacteria, and have succeeded in growing the live tissues of embryos in artificial media. It has been proved time after time that the epithelial cells of an embryo, such as the living cells of renal tubules, if grown apart from other cells, spread outwards in a more or less disorderly manner; but if connective-tissue cells are added to the culture, then the epithelial cells form orderly ranks, just as they do in the kidney tubules of the embryo.[13] Carrel[14] found that the juices of embryonic tissues contain substances which cause cultures of living cells of any kind to proliferate rapidly and to continue alive for an endless series of generations. Thus it will be seen that the machinery which regulates the behaviour of groups of cells within the body of the embryo is one of the utmost complexity, and yet is of a kind which can be handled and studied by biologists. Nor can we doubt for a moment that the machinery of development and of growth which we find at work in the embryo is also the machinery of adaptation and of evolution. In every phase of the development and evolution of the human hand we see this adaptational machinery at work.

Behaviour of Young Nerve Cells.

There is no need to tell even the uninitiated that the brain and nervous system of man comprises many thousands of millions of microscopic units or nerve cells. Each unit of the brain has its appropriate place in a tremendously complex system, and has its special duty in dealing with the tide of messages which flood that system in every hour of conscious and subconscious life. When a child is born all the nerve centres which regulate the complex apparatus of breathing start into instant and effective operation. When the mother's teat is placed within its lips the nerve centres which regulate this intricate series of actions start to work as if they had served an apprenticeship before they appeared in the orderly development of the babe's nervous system. We cannot yet explain satisfactorily the means by which such really marvellous evolutionary results have been reached, such as reflex nerve centres, ready for action at the moment of birth, but at least we can claim to have before us a prospect of giving a rational account of how the various groups of nerve units are assembled so as to give a functional result.

Our present knowledge of this matter is largely due to the researches of Dr. Ariens Kappers[15] of Amsterdam, and to investigations made by his pupils. Nerve cells may not remain in the sites at which they are developed; in their younger stages they have the power to migrate. Dr. Kappers found that a group of embryonic nerve cells or neuroblasts, which are afterwards to control definite sets of muscles and therefore to be concerned in carrying out certain actions of the body, migrate towards the sources of their information. Those young executive nerve cells take up their permanent stations at points most suitable for the performance of their life's work. If we conceive a mob of war-seasoned men to deploy automatically and to take up effective battle-stations we have before us a picture of what is to be seen taking place among the nerve cells in the brain of the growing human embryo. Developing nerve cells send out processes which effect unerring contacts with other distant cell-groups of the body. Dr. Davidson Black[16] found that certain cell-groups on the cortex of the brain proceeded in their development only if the processes of another distant group of cells had entered into contact with them. We have here another instance of one embryological group of cells determining or controlling the development of another group. Enough has been said to show that the machinery which regulates the development and growth of the brain is one of the utmost complexity. We have no reason to suppose that it is of a kind which lies beyond the comprehension of the human mind, although it may take centuries of neurological inquiry to lay bare its nature. The one point we are certain of is that the factors which regulate the development, growth, and arrangement of the countless units of our nervous system do work in such a way as to produce an effective functional result.

The Evolution of Muscular Adaptations.

In no system of the human body do we find more instructive examples of mechanical adaptation than in the muscles which carry out the movements of our bodies and of our limbs. The nature of the machinery involved in the elaboration of muscular adaptations may be illustrated by the development of muscles which guard the mouth, eye, nose, and ear, and are concerned in expression. The bud which gives rise to the muscles on one half of the face begins at one localised site of the human embryo, a site in the embryonic neck, marked by the hyoid arch. From this site the young muscle cells or myoblasts migrate outwards, over the neck and scalp, round the ear, eye, nose, and mouth; as they reach their destinations they fall into ranks and take up such positions as permit

[13] Ebeling and Fischer, *Journ. Experim. Med.*, 1922, vol. 34, p. 317.
[14] See A. H. Drew, *British Journ. Experim. Path.*, 1922, vol. 3, p. 20.
[15] "Further Contributions to Neurobiotaxis," *Psychiat. en Neurolog. Bladen*, 1916, Nos. 5, 6.
[16] *Journ. of Comp. Neur.*, 1913, vol. 23, p. 351.

them, when fully differentiated, to perform effectively their respective functions. The influences which control their movements and regulate their dispositions we do not know as yet. But whatever the nature of these regulating forces may prove to be, we can see that they are exactly of the same kind as those which control the differentiation of facial musculature in monkeys and anthropoids. The degree of differentiation of the facial musculature of man is but the final stage of a continuous series of evolutionary forms to be traced in the faces of monkeys and anthropoids. The elaboration of the facial musculature runs more or less parallel to the elaboration of the brain.

The manner in which muscular adaptations arise may be better exemplified if we take a muscle which is concerned in purely mechanical actions, such as the latissimus dorsi. This muscle is concerned in pulling the upper arm backwards as in rowing. It works in the human body from a wide firm base, placed in the lower part of the back—one which extends from the sixth dorsal spine to the crest of the ilium. As points of origin it also utilises the lowest three or four ribs, and occasionally also the lower angle of the scapula. This muscle, occupying the lower half of the back, makes its appearance in the human embryo in the lower part of the neck, just below the embryonic shoulder-blade. By the end of the sixth week of development the army of cells which compose the muscle have extended or migrated downwards as far as the fourth rib, reaching the twelfth rib about the seventh week, and the iliac crest by the time the human embryo is two months old.[17] The success with which the developing muscle cells reach their ultimate destinations is one of surprising accuracy; they may take hold of a spine or a rib too far up or too low down, but the total result is always one which makes the whole muscle into an effective mechanical engine. Such variations may make the muscle a little less or a little more useful to the individual. The young muscle cells, when they have reached their definitive sites, arrange themselves in serried ranks, each rank hitched directly or indirectly to the lever through which the collective army of cells exerts its strength.

Now, this muscle has almost the same attachments in the gorilla and chimpanzee as in man; there is a greater range of individual variation in its points of origin; the marksmanship made by the migrating myoblasts is less accurate than in man. In the orang this muscle obtains no direct origin from the ribs, while in the gibbon five or six ribs are seized. In the gibbon, however, there is no direct muscular origin from the crest of the ilium. In the old-world monkeys, and also in their American cousins, the origin of the latissimus is restricted to the lower three or four dorsal spines; the origin from the iliac crest is slight or indirect; while the fibres rising on the side of the thorax are not directly attached to the ribs. Very occasionally one sees fibres rising from the lower angle of the scapula of monkeys, a variation in attachment which has become very common in man. In these variations of attachment we are seeing evolution at work, and its machinery lies in the forces which regulate or control the migratory movements of the young muscle cells.

[17] Warren H. Lewis, Keibel and Mall's Manual of Human Embryology, 1910, vol. i. pp. 454-522.

Influence of Nerve-connections.

It is true that nerve fibres have entered, and formed a union with, the muscle mass in the neck before migration has set in; the nerves are carried along by the migrating muscle horde; differentiation of the muscle fibres begins at the point at which the nerve enters the muscle mass. When muscular fibres are fully differentiated they depend on their union with nerve fibres for a continuance of their health and life. But the migratory impulse, be that impulse what it may, lies not in the nerve union but in the muscle elements themselves, for Ross G. Harrison[18] found, if the limb of a developing tadpole were deprived of its nerve supply, the muscles still became duly differentiated in their usual stations.

Adaptations may appear first as occasional Variations.

Let us take another example to illustrate the manner in which a new muscular feature has been evolved in man's body. The muscles of the calf of man's leg have taken on an enormous growth to raise the heel in walking. The structure of the deeper muscle of man's calf, the soleus, has taken on an extremely complex and efficient arrangement of fibres; its origin from the posterior aspect of the bones of the leg is particularly extensive. In all dog-like or pronograde apes this muscle has a narrow origin from the smaller bone of the leg, the fibula, and this is also usually the case in the orthograde apes, or anthropoids. In man the origin of the muscle has undergone an extension, a large part migrating from the fibula and obtaining an extensive attachment to the tibia. But this extension to the tibia which is constant in man occurs as a frequent variation in all the anthropoids. Out of 8 gorillas examined, 3 had a tibial origin for this muscle; this was also the case in 2 out of 12 chimpanzees, 1 out of 8 orangs, and 2 out of 12 gibbons. In the anthropoids there is a tendency for the soleus to extend its origin to the tibia; in man this tendency

[18] *Anat. Record*, 1908, vol. 2, p. 145; *American Journ. of Anat.*, 1906, vol. 5, p. 121; *Journ. of Experim. Zool.*, 1907, vol. 4, p. 239.

has become a fixed habit. This is but one instance of what is often to be observed in the study of human evolution, where an occasional variation in apes has become the established form in man.

How has this tendency to vary in a definite direction arisen? It is a direction which increases the functional efficiency of the human leg. Has this tendency arisen in apes as a result of the manner in which they climb? Or is it, as Huxley would have us infer, a tendency which is inherent in the developing soleus and has come into existence under the influence of some unknown factor which regulates the developmental movement of muscle cells? I think that Huxley's interpretation is the true one.

Let us take another example. Under the skin of the sole of man's foot lies a muscle known as the short flexor of the toes. In man all its four bellies, designed for the outer four toes, have a solid basis of origin on the bone of the heel; from such an origin the collective muscle can play a helpful part in maintaining the arch of man's foot. Now in the monkey's foot, while the muscle for the second toe arises from the heel, the muscles for the three outer toes retain a primitive origin from an adjacent surface provided by moving tendons. In the gibbon it is usual for the muscle of the third as well as of the second toe to have moved its origin to the heel; in the great anthropoids, particularly in the orang, the muscle of the fourth toe has also left the tendon and migrated to the heel; in man all four have moved. Here we see a human character arising as the culmination of a tendency which can be observed, to a greater or less degree, in the feet of all those animals which are most closely related to man, yet more primitive than him in structure. The migration of origin, on the part of the embryonic muscular cells, is of a useful or purposive kind. We cannot avoid the conclusion that the growth and development of young muscle cells are controlled by influences or means which work towards a functional result.

The Origin of a Muscle peculiar to Man.

Man possesses a muscle which is peculiar to himself —the peroneus tertius—and it will help us to understand how new structural features have been, or are being, evolved if we note the manner in which this muscle makes its appearance during the development of the leg and foot of the human embryo. The peroneus tertius raises the outer border of the foot and assists in applying the sole of the foot to the inequalities of the ground in walking. If we examine a hundred human legs we shall find ninety in which the peroneus tertius is a complete and separate muscle, but in the remaining ten we shall find some in which it is separated only to a greater or less degree from an adjacent and older muscle, the long extensors of the toes, and some in which it is quite unseparated from this muscle, as is the case in the legs and feet of anthropoid apes. In the gorilla one notices occasionally a tendency for the outer fibres of the tendon going to the fifth or small toe to stray or migrate towards the outer border of the foot. When we turn to the developing leg to ascertain how this new muscle makes its appearance in the human embryo, we find, towards the end of the second month of development, that the mass or colony of muscle cells which are to extend the toes, becomes separated from the common extensor mass of the leg, and that, in turn, the muscle cells which are to form the peroneus tertius separate or are cleft from the outer side of the long extensors of the toes—from the part concerned in extending the little toe and incidentally in turning upwards the outer border of the foot. The peroneus tertius represents a colony of muscle cells which have broken away from the parent muscle—the long extensor of the fifth toe. The tendon fibres have broken away from those going to the toe and migrated backwards along the outer border of the foot, thus giving them an advantageous position for the performance of their function in walking.

We have here all the properties manifested by developing muscle masses—a power of cleavage or separation, and a power of migration. What causes these outer muscle cells which are destined to act on the most external of the digits to break from the parent mass and assume a separate functional identity? I agree with Huxley that there are no grounds for believing that the behaviour of embryonic muscle cells is in any way influenced by experiences gained by adult muscle fibres. When vertebrate limbs came first into existence the muscle colonies which deployed to form the extensors of the toes, grouped themselves so as to get a functional result. In the case of the outer toe there was a double function, the extension of the toe and the everting of the foot. In the human foot the muscle cells which evert the foot have separated themselves from those which extend the little toe. The evolutionary machinery lies in the behaviour of the embryonic muscle cells or myoblasts.

Instances of Parallel Inheritance.

Let me cite two other examples which go to show that myoblasts possess evolutionary tendencies which work towards a purposive or functional end. The interosseus muscles of the hand and foot of monkeys arise, not from the adjacent surfaces of metacarpal and metatarsal bones, as they do in man, but from the bases of these bones, in the palm of the hand and sole of the foot. In the human embryo the interosseus muscles appear in the same palmar position as that which is retained in monkeys. In the most primitive of anthropoid apes—the gibbon, and also in the highest of South American monkeys—the howler monkeys—Ateles—the origin of the interosseus muscles have migrated so as to take a partial hold of the adjacent surfaces of the metacarpal and metatarsal bones. In the great anthropoid apes—the gorilla, chimpanzee, orang—and in man, these muscles have sunk in between and seized the adjacent surfaces of the metacarpal bones of the hand and metatarsal bones of the foot. This migratory tendency has seized upon, or become manifested in, the muscles of the hand as well as in those of the foot, although these members are subject to different functional influences. We can account for such evolutionary manifestations only by supposing that in a remote common ancestor of all the members of the higher primates there was a latent tendency in the myoblasts of the interosseus muscles to deploy

and group themselves in a new way, one which gave a better functional result.

Another striking fact is that the muscles which have become reduced or vestigial in man have also become reduced and vestigial, although usually to a less extent, in the anthropoid apes. All of these muscles, plantaris, palmaris longus, psoas parvus, latissimo-condyloideus, omo-cervicalis, etc., are laid down in a normal way during the development of the embryo; after being laid down retrogression sets in. We have here again to deal with functional tendencies. The machinery of reduction is resident in the processes which govern the development of structural systems in the embryo. As W. Roux supposed, there may be a struggle for survival between the system of cells which make up the body of an embryo.

The Adaptational Properties of Bone Cells.

By the fourth month of fœtal life young nerve cells and young muscle cells have taken up their definitive position and arrangement. On the other hand, white blood corpuscles retain all through the life of the individual the migratory power which is lost by most other cells of the body early in fœtal life. The cells which line blood and lymph vessels and those which line the peritoneal and pleural cavities[19] retain all through life a power to proliferate and produce new tissues which are of a purposive kind. Such cells retain the chief characteristic of embryonic cells—the power to arrange themselves as part of a functional complex. Bone cells also retain powers of purposive action. Nothing is better known than that, if a bone of a rickety child bends under the weight of the body, the bone cells lying in its concavity will proliferate and build a buttress to strengthen the shaft. It is not necessary for us to speculate here as to the exact stimuli which cause bone cells to behave in this manner; it is enough for our present purpose to note that they react to fulfil an end necessary for the occasion.[20]

John Hunter discovered the remarkable power which bone cells possess to remodel bones during growth. While bone cells are building at one part of a bone, they are, at another part of the same bone, busily engaged in taking down their previous handiwork. The co-ordinated manœuvres of the armies of bone cells concerned in the growth of the jaws and eruption of the teeth are extraordinary. When teeth are erupting and also long after they are cut, their bony sockets are being constantly altered and remodelled by the hundreds of thousands of osteoblasts embedded in the bone surrounding the dental roots. While new bone is being laid down on the outer side of the jaw under the gum, the corresponding bone on the inner side of the gum is being absorbed. But in the tooth socket itself the opposite is happening; new bone is being laid down on the inner side of the tooth socket, while it is being removed from the wall forming the outer side of the socket. New bone is being laid down under the roots so that the socket as a whole is being raised and moved in an outward direction. The crowd of osteoblasts involved in this operation are clearly co-ordinated in their action; they move on towards a functional result. Although we do not know the exact means by which their action is co-ordinated we have, in the qualities and tendencies, possessed by bone cells, part of the machinery of evolution. Cartilage cells, during embryonic life, must be co-ordinated in their growth and arrangement. In the fœtal hand we find they have fashioned the joints to meet the needs of the muscles which act on them, thus permitting harmonious movements of the wrist and digits. The development and behaviour of embryonic cartilage cells constitute part of the machinery of human evolution.

[19] An account of the actions and reactions of vascular tissues will be found in the writings of W. Roux from 1878 onwards. I have dealt with the adaptative reactions of peritoneal cells in Human Embryology and Morphology, 1921, 4th edition.

[20] I have dealt with the growth reactions of bone cells at some length (Menders of the Maimed, 1919, chapters xiv., xv., xvi., xvii., and xviii.)

Co-ordination in the Growth of Bone, Muscle, and Nerve Cells.

I have dealt with the behaviour of young cells of bone, muscle, and nerve centres in the developing embryo in order that we may appreciate the complexity of the process involved in producing a new structural adaptation of the human body. When we sit up or walk, our vertebræ are balanced one upon another by means of a complex series of muscles acting upon an equally complex series of levers, the whole controlled by intricate groups of nerve cells situated in the spinal cord and brain. The anatomical evidence[21] leaves us in no doubt that the spinal mechanism of man has been evolved from one very similar to that now seen in the anthropoid apes. Indeed in the young chimpanzee and gorilla many of man's spinal adaptations are already present. In the evolution of a human from an anthropoid spine we have to conceive, (1) that the multitudes of bone cells involved in the building of vertebral processes of the embryo were so influenced in their operations that the levers they built were altered in strength, inclination, and form; (2) the countless myriads of myoblasts involved in the formation of the spinal musculature were so influenced that they took up new positions and effected new combinations; (3) the cartilage cells, which mould the contours of the intervertebral joints, were moved to alter the shapes of the articular surfaces so as to provide the needed contours; (4) the nerve cells of the spinal cord and brain, presiding over the reflex and voluntary movements of the spinal muscles, had to undergo increase in numbers, rearrangements in grouping, and readjustment of contacts. We have to postulate that in the human embryo there exists a machinery which co-ordinates the development and growth of all the diverse hordes of embryonic cells concerned in the formation of man's spinal mechanism and causes them to move in a direction which, at all stages of evolution, yields a harmonious functional result.

Theory of Hormones.

There is only one theory which affords a rational explanation of how such complex adaptations can be brought about—the theory of Hormones postulated by Starling in 1905.[22] Although Prof. Starling devoted

[21] "Man's Posture: Its Evolution and Disorders," *Brit. Med. Journ.*, 1923, 1, pp. 451, 493, 545, 587, 642, 669.

[22] Prof. E. H. Starling, "The Chemical Correlation of the Functions of the Body." The Croonian Lectures at the Royal College of Physicians, *Lancet*, 1905, vol. 2, p. 339.

the greater part of his Croonian lectures to demonstrate the part played by chemical substances or hormones in co-ordinating the functions of the body he clearly realised that hormone control formed the basal machinery of all evolutionary processes in the animal kingdom.

"In the lowest organisms, such as the bacteria and protozoa, the only adaptations into which we can gain any clear insight are those to the environment of the organism, and in these cases the mechanism is almost entirely a chemical one. . . . In the lowest metazoa, such as the sponges, there is still no trace of any nervous system. The co-ordination between the different cells of the colony is still determined by purely chemical means. . . . If, as I am inclined to believe, all the organs of the body are regulated in their growth and activity by chemical mechanisms, similar to those I have described, an extended knowledge of hormones gives complete control of the body."

We are justified, on all grounds, in looking upon the human embryo, in the earlier stages of its developing, as a colony of protoplasmic units or cells, organised under a system of government controlled by hormones. Each member of the colony, we must suppose, has the power of circularising, by means of the hormone postal system, some or all of the other members of the colony in such a way as to notify its needs and compel their co-operation. With each step in the differentiation of the embryonic tissues there must be a further elaboration in the hormone system of intercommunication and government, until the fœtal stages are reached, when the growth-regulating substances become installed in special controlling centres represented by the glands of internal secretion—the pituitary, adrenal, thyroid, etc. We know that juices expressed from embryonic tissue contain substances which stimulate the proliferation and growth of living tissues; we know from observations already cited that one group of embryonic cells can control the manner in which another group develops, but we have to admit, also, that our knowledge of the action of hormones in fashioning the growth of organs is still in its infancy. The vista presented by this unexplored field of knowledge is infinite in extent and complexity, and will provide embryologists with many centuries of labour. Their labour will reveal in full the true nature of the machinery which underlies the production of structural adaptations which occur in every part of the animal body in every stage of its evolution.

The Significance of Acromegaly.

A long and close study of the bodies of men and women who have been the subjects of that strange disorder of growth known as acromegaly, has convinced me that the system of hormones, which controls and co-ordinates the growth of various organs and parts of the body is organised, like the nervous system, on a reflex basis. There are reflexes of growth just as there are reflex actions of muscles; both kinds of reflexes serve definite purposes in the economy of the body. The glands of internal secretion provide substances which control the action of organs and of parts of the body; they also produce substances which co-ordinate the growth of the organs or parts concerned in these actions. In the subjects of acromegaly the pituitary gland is enlarged and its structure more or less disorganised; the parts of the body which respond to hard toil, such as the hands, feet, and jaws, become greatly and irregularly overgrown. All the systems of the body—muscular, bony, respiratory, circulatory, alimentary, and renal systems—are involved; all show an abnormal degree and kind of overgrowth.

We find a clue to most of the growth disorders of the human body, such as acromegaly, in a knowledge of the mechanism of normal growth. Growth disorders—dwarfism and giantism—are but derangements of the various parts of the normal machinery of growth. Sir James Mackenzie regards the symptoms of illness, manifested by suffering men and women, as derangements of the normal reflex functions of their bodies. In a like manner we may consider disorders of growth, such as acromegaly, as a derangement of a normal mechanism—that which co-ordinates the response made by the various parts of the body to exercise and training. When a man passes into training, whether it be to use his hands as a labourer, his biceps as a blacksmith, his legs as a runner, or his arms as a rower—the responsive growth is not confined to the muscles of his hand, arm, or leg. All the bones of the body respond to a greater or less degree, so do the heart and lungs, so do all the systems of his body; he has to eat and digest more. We cannot imagine such a co-ordinated functional result being brought about, one which affects every system of the body, unless we postulate a controlling system of hormones. Nor can there be a doubt that acromegaly, in all its stages and degrees, represents a diseased manifestation of this adaptational system.

To fit all the bits of this puzzle into a connected whole we have to suppose that muscles in sustained action do emit certain substances which pass into the circulation and thus reach the pituitary gland. We have to suppose that in the pituitary these substances elicit responses leading to the emission of other substances which pass into the circulation and thus reach and influence organs which are correlated in action with the muscles directly involved. We have here all the elements of a reflex system—the pituitary serving as a chief centre or hormone-brain. In acromegaly the disordered condition of the pituitary leads to a flooding of the body with adaptative hormones after the most trivial of muscular actions, and hence its unregulated growth.

Barwell's Disorder.

In the Museum of Charing Cross Hospital, Huxley's old school, there is the skull of a boy which shows a very instructive disorder of growth. It is not a unique specimen; many cases of an exactly similar kind are known. The boy came into the hospital for treatment of a tumour-like swelling of the face, for which Mr. Barwell tied the right carotid artery. The boy died, and it was found that, on the right side of his skull, all those structures which are concerned in mastication, and only the structures concerned in this function, were greatly and uniformly hypertrophied. The condition was clearly produced long before birth, for all the teeth, including those of the milk dentition, were nearly twice the normal size on the right side of the mouth. So were the jaws and all the bony struts of the face which

support the jaws; so were the muscles of mastication, the temporo-mandibular joint—in short, all dental, bony, muscular, vascular, and nervous structures concerned in mastication. We cannot conceive how such disorders of growth could be so sharply limited to a single functional system unless we agree that the machinery which regulates growth and development is organised not on an anatomical, but on a functional basis.

Use-inheritance.

In the foregoing paragraphs an attempt has been made to picture the means by which the development and growth of the various cell groups, which make up the body of the embryo, are co-ordinated and controlled. Such evidence as we have justifies us in the belief that there is an automatic system of control worked by means of hormones, and that this machinery, in all its variations, tends to produce a functional or adaptational result. The very important question remains to be considered: can this machinery, which controls the differentiation of the tissues of an embryo, be influenced from without? Or does it, as Bateson believes, work on towards its destined result, in spite of all surrounding conditions and influences? The genital glands and their contents, of both man and woman, are exposed to all the substances, be they nutritive or hormonic in nature, which flood their circulatory systems. In 1906 J. J. Cunningham [23] applied the theory of hormones to the problems of heredity. He conceived it possible that the genital cells could be influenced, and so altered in their constitution, by hormones thrown off by all the organs and parts of the parent body. There is no inherent physical obstacle to prevent one from entertaining such a belief. Such a conception implies the possibility of hormones—function-regulating substances—of a parent coming into contact with and influencing the controlling action of the embryonic hormone-system. If it were possible, as is assumed in every form of Lamarckian belief, for parent products to come in contact with, and thus alter, the machinery which controls the growth of the embryo, it would be a consequence of the utmost import for mankind. By a full use of our brains, of our teeth, or of our hands, we might hope to influence the development and growth of the corresponding parts in our children.

Evidence of the Teeth.

I have selected the teeth to test the question as to the part played by use in the evolution of structural adaptations. There can be no doubt that the manner in which the crowns of man's sixteen upper teeth fit against corresponding surfaces of the lower sixteen, give us as fine a structural adaptation as we may hope to cite. There is the additional advantage that, as the teeth are the most persistent of fossil remains, we know more of this system in the forerunners of man and of living anthropoid apes than of any other parts of their anatomy. Further, in highly civilised races teeth are not only more liable to decay and to irregularities of eruption than in primitive races, but there is also, in civilised peoples, a marked tendency to a reduction in size and number of the dental series. We see, too, in the evolution of the dentitions of the higher primates, when the pattern of the enamel changes in one tooth, it changes in all of them; if one tooth alters, the opposing teeth have to alter in conformity; we see that if the dentition strengthens, all the members of the series participate; when reduction sets in, all the teeth suffer a reduction in a definite order. But these changes cannot be due to use, for the crowns of the teeth are laid down, and the opposing chewing surfaces fully formed, while the dental germs lie buried in the gums and long before the crowns come into use. When they do come into use, the teeth formed in the upper jaw possess the exact surfaces needed to oppose those of the lower jaw. After usage, especially in apes and primitive man, the opposing surfaces become worn off; if use had any effect here it would be to produce teeth with eroded crowns.

It is clear that functional adaptation, so far as concerns the production of teeth, is a property resident in the embryonic tissues; the effects of usage in the parent can have no influence on the machinery which shapes the dental crowns in the mouth of the fœtus and infant. If this is true of one system of the human body, it is probably true of all other adaptational systems—such as the brain, hand, and foot. Nature would have been foolhardy to entrust the future of any race whatsoever to the voluntary efforts or natural inclinations of the parents. As far as possible she seems to have safeguarded the progeny by isolating the gonads from the functional influences of the parental body.

The Germ-plasm can be permanently injured.

Yet there is one line of evidence which shows that the spermatozoa of the male and the ova of the female can be acted on or injured from without. Darwin [24] has related the case of a cow in which one eye was injured when she was in calf. The calf was born with the corresponding eye small and blind. In more recent years Marey [25] has recorded an identical result in a mare; one eye was injured when she was pregnant, and the foal was born with the corresponding eye small and blind. Hitherto we have been inclined to regard such cases as mere coincidences, but the well-known experiments of Guyer and Smith [26] provide a rational explanation. They injected into the veins of doe rabbits, about the end of the second week of pregnancy, doses of a substance which has a selective and toxic action on the lens of the eye. Many of the young were born with defects of the eyes—cataract of the lens being particularly frequent. When these young rabbits grew up and bred, many of their young showed the same defects. The developmental disorder could be transmitted in the spermatozoa as well as in the ova. These experiments show that the germ-plasm can be reached from without, and by means of a toxic substance can be permanently injured, so that progeny issuing from it will show ever afterwards a characteristic and localised defect. Prof. Ch. R.

[23] Hormones and Heredity, 1921.

[24] Variations in Plants and Animals under Domestication, 1868, vol. 2, p. 34.

[25] Le Déterminisme et l'adaptation morphologique, R. Anthony, 1922, p. 88.

[26] M. F. Guyer and E. A. Smith, *Journ. Experim. Zoology*, 1921, vol. 31, p. 171.

Stockard [27] induced permanent changes in the germ-plasm of guinea-pigs by exposing one generation of animals to extreme and continuous doses of alcohol. Dr. J. G. Adami [28] cites several instances of a similar nature, and has summed up the evidence relating to "the inheritance of acquired conditions in the higher mammals." Many of the cases recorded to prove acquired inheritance relate to changes which have been produced in the skin, particularly in its pigment-carrying cells. On the evidence which has accumulated there is good reason for believing that light can act upon epidermal and other elements of the skin in such a way as to effect changes in certain factors or elements of the germ-plasm. The observations and experiments made by J. T. Cunningham [29] on the colouring of flat fish, and the more recent observations which Dr. Kammerer [30] has made on salamanders exposed to light, and to dark backgrounds, can be interpreted only if we admit that reactions in the skin can affect the reproductive cells lying within the genital glands of the animals subjected to experiment. Notwithstanding this admission I do not think, as I shall mention later, that the loss of pigment in fair Europeans is due to any direct action of light on the skin. It is one thing to injure or influence the germ-plasm in such a way as to alter the machinery which controls the development of the embryo; it is quite another thing to alter that machinery in such a way as to make it produce a new mechanical adaptation. We know of no means by which the machinery of mechanical adaptation can be altered from without.

Are the Modern Conditions of Life altering the Germ-plasm of the Human Stock.

The admission that the genital cells can be injured or altered by substances circulating in the body of the parent is of the utmost consequence for mankind. The conditions of modern civilisation are making us the subjects of a colossal experiment. Six thousand years ago, our ancestors, scraping a subsistence from moor and shore, passed their days amidst the same conditions as surrounded the earliest types of evolving man. Man's body was adapted for rough fare and unregulated exposure. Modern civilisation has revolutionised the conditions of life in every detail. We use our brains, our skins, our muscles, our lungs, our teeth, stomach, and bowels, our hands and feet, for purposes which are new to them. Our tissues are kept soaked with juices containing substances which are still strange to them. Our crowded communities favour the prevalence and spread of all forms of infectious disorders in young and old. We are discovering that a rough and raw dietary contains certain elements which are essential for health. It would be strange if the evolutionary machinery of the human body kept on working in the same way as when the conditions of life were, if not simpler, yet much more primitive. A prolonged and minute comparison of human remains found in ancient and modern graves in England has convinced me that structural changes of a minor kind are affecting certain parts of the skeleton in at least one-third of modern instances. The narrow bony opening to the nose, with its jib-like nasal spine, its raised and sharp sill, so often seen in modern English skulls, are conditions never present in Englishmen of the pre-Roman periods. Contracted palates, crowded and defective teeth, deformed jaws, sunken cheek-bones do not become common in English graves until we reach the eighteenth century. The appearance of these structural changes in Englishmen cannot be attributed to the introduction of any new racial element from abroad. No doubt these facial changes are due in part to the soft nature of our food, and the disuse of our muscles of mastication.

Lack of use alone will not, however, explain the form taken by these structural alterations; they are injurious rather than helpful; they cannot be classified among the contrived adaptations. We have reason to suspect that defects of eyesight grow more common. There are grounds for believing that the great bowel, including the cæcum and appendix, becomes more liable to disorder and to disease with each succeeding generation. Twenty years ago Metchnikoff [31] expressed the belief that the great bowel of man had become a useless structure, and that he would be better off without it. The result of recent surgical experience has been to convince medical men that the man with a normal great bowel is an infinitely fitter and happier person than the man without one. The only question that remains to be settled is whether it is better to be with or without a colon which has become incurably diseased.

There is thus a certain amount of evidence to support the belief that certain parts of the body are less robust, some of them actually undergoing a structural change, in a considerable proportion of people living under modern conditions of life. There is also no doubt that these changes and susceptibilities occur much more frequently in some families than in others. To what extent these new features have become hereditary and therefore due to an injury of the germ-plasm, we cannot yet say. But in the light of experiments like those of Guyer and Smith, and of Stockard, medical men have grounds for suspecting that the source from which new generations of our race issue may not be invulnerable, that our germ-plasm may become tainted under the conditions to which our bodies are now subjected.

The Law of Recapitulation is only partially true.

In the foregoing paragraphs I have turned aside from my main thesis—the nature of the evolutionary machinery which has given man his gifts of brain and body. The nature of this machinery will never be understood by those who still harbour the belief that the human embryo, in its developmental stages, recapitulates the evolutionary history of the human body. I do not think any one familiar with the stages passed through by the developing human embryo would now agree with Huxley when he wrote: [32]—

[27] "An Experimental Study of Racial Degeneration in Animals treated with Alcohol," *Archiv Int. Med.*, 1912, vol. 10, p. 369; Proc. Soc. Experim. Biol. and Med., N.Y., 1911–12, p. 71; 1913–14, p. 136.
[28] Medical Contributions to the Study of Evolution, 1918, ch. v.
[29] Hormones and Heredity, 1921.
[30] Nature, 1923, vol. 111, p. 637.
[31] The Nature of Man, translated by Dr. P. Chalmers Mitchell, 1903; see also Keith, "The Functional Nature of the Cæcum and Appendix," *Brit. Med. Journ.*, 1913, vol. 2, p. 1599.
[32] Collected Essays, vol. 2, p. 5.

"A man in his development runs for a little while parallel with, though never passing through, the form of the meanest worm, then travels for a space beside the fish, then journeys along with the bird and the reptile for his fellow-travellers; and only at last, after a brief companionship with the highest of the four-footed and four-handed world, rises into the dignity of pure manhood."

It is true that we cannot explain the infinity of stages passed through by a human embryo, from the fertilised ovum, representing the lowest unicellular stage of living things, to the fully formed child, unless we believe that man, like all animals, has been evolved from the simplest of beginnings. But every one of these transitional stages represents a new form of being, never one of which has been seen at any stage of the world's history leading an independent adult existence. Every organ and part of the human body passes through an extensive series of developmental changes which receive a full and adequate explanation from the theory of evolution, but not one of these changes, from the first to the last, copies a form seen in any adult animal; at every point of development old or recapitulatory phases are masked by the unceasing introduction of new and individual features. The student of the human embryo and fœtus is impressed not by its recapitulatory behaviour but by the manner in which new features are being intercalated. Such facts favour Huxley's view that the machinery of evolution works in the body of the embryo uninfluenced by adult experience.

The Use made by Nature of the Capitalistic System.

Scientific men do not need to be told that capital is needed for the development and improvement of an invention; capital is as necessary for the progress of a civilisation as for the extension of a business undertaking. Nature discovered very early in the history of the world that capital is needed for evolutionary progress. A breakfast egg represents the capital set aside for the development of a fowl, and during the incubation period the stock of yolk makes possible any form of experiments which the embryonic cells may tend to make. In the higher mammals the capitalistic system has become fluid and elastic—represented by the mother's blood and milk. The placenta and all accessory structures needed for the lodgment of the young in the mother's womb were invented and elaborated by embryonic cells during the incubating stages in the development of lower vertebrates. The simple yolk capitalistic system, evolved and elaborated by the embryonic cells of lower vertebrates, became, in the higher vertebrates, transformed into the elaborate organisation which gives rise to the placenta, thus securing for the young months of free lodging. When we inquire into the nature of the process which gives rise to the placenta we find that it concerns certain embryonic cells which, in the lower vertebrates, proceed to form part of the belly-wall, part of the bowel, and part of the bladder. These same groups of cells in higher mammals have taken on themselves an entirely new purpose. Instead of proceeding to form the parts of the body just mentioned, they give rise to the placenta and membranes which envelop the embryo. Here we see that embryonic cells and the machinery which regulates their evolutions have inherent in them a power of working out the most intricate inventions and of effecting structural adaptations of the most serviceable kind.

The Genesis of Man's special Structural Features.

We need not be surprised, seeing how plastic and resourceful the embryonic tissues are, to find most—but not all—of man's characteristic features appear in a modified form as transitional phases in the fœtal stages of man's nearest allies—the anthropoid apes. Man's outstanding structural peculiarities have been produced during the embryonic and fœtal stages of his evolutionary history; the corresponding and somewhat similar characters which appear in fœtal anthropoids become masked in these animals by the superaddition of coarser animal features which develop as their intra-uterine life closes, and particularly as their adolescent and adult stages are passed. At birth the brain of the baby gorilla is almost as big as that of the human baby; but whereas the period of rapid growth continues in the human brain throughout infancy, the brain of the gorilla proceeds after birth at a slow pace. The human brain retains the rapid rate of fœtal growth for two years after birth. My friend Prof. L. Bolk[33] of Amsterdam, who has done so much to prove that man's distinctive characters represent a heritage accumulated in the fœtal phase of his development, has shown that the downward bend of the front part of the base of the skull, and the consequent backward position of the face, occur at an early point of development in all mammals. The cranial bend becomes undone and the face thrust forwards as development proceeds in all mammals, save in man, in whom these fœtal features are retained until, and throughout, adult life. The nearest approach to the adult human form occurs in the fœtal stages of anthropoid apes. The fœtal cranial bend is not a primitive or ancient character; it was worked out in fœtal life; never, until the evolution of man took place, did this feature survive to reach an adult stage.

Let us take another feature—man's hairless skin, and in the case of the white races its comparative lack of pigment.[34] In the chimpanzee fœtus, at the seventh month of development, the hair is distributed on the body exactly as in a baby at birth; there is the same long and fine hair on the scalp; the same smooth skin covered with a short, almost invisible down. The skin, too, which afterwards becomes deeply pigmented and black in the adult chimpanzee, at this stage is gray, tinged with a trace of brown. At a still younger stage the skin is almost free from pigment. The young of many of the higher primates are born with fair hair—often tinged with red. Fair hair is a fœtal character of primates which has become permanent in Northern Europeans and is found distributed

[33] "The Problem of Orthognathism," *Proc. Konin. Akad. van Wetensch. te Amsterdam*, 1922, vol. 25, Nos. 7, 8; "On the Significance of Supra-orbital Ridges in the Primates," *ibid.*, 1922, vol. 25, Nos. 1, 2; "On the Character of Morphologcal Modifications in consequence of Affections of the Endocrine Organs," *ibid.*, 1921, vol. 23, No. 9.

[34] See my Herter Lectures, "The Evolution of Human Races in the light of the Hormone Theory," *Johns Hopkins Hospital Bulletin*, 1922, vol. 33, pp. 155, 195; also Prof. C. S. Stockard's "Human Types and Growth Reactions," *Amer. Journ. Anat.*, 1923, vol. 31, p. 261.

sporadically in North Africa and Central Asia. Here again we see characters which were worked out in fœtal months passing on to become characters of adult life.

Such examples could be multiplied to a wearisome extent. I do not wish to minimise the number and importance of transient simian features which appear in the body of the human fœtus and infant; they are well known and of great significance. But I do desire to give a true interpretation to such human features as are represented by man's small face and jaws; his forehead, tending to be devoid of supra-orbital ridges; his large head poised on a long and relatively slender neck: they are features first produced in the fœtal stages of higher primates and now retained by man in his adult state. The tendency to preserve such fœtal characters is seen in certain genera of South American monkeys. But all the fossil progenitors of ape and man we have yet discovered have a face, jaws, skull, and neck of the more primitive and bestial type.

The Bearing of Fœtal Inheritance on Huxley's Conception.

I return to Huxley's disbelief in "use-inheritance" and to his conviction that animals—including man—tend to evolve "along their predetermined line of modification." It is clear that the mammalian placenta, particularly that kind of placentation which occurs in the womb of man and of anthropoids—identical systems—cannot in any way be accounted for by "use-inheritance." They have been worked out by properties inherent in embryonic tissues. The fact that the most characteristic features of the human body appear first in embryonic or fœtal life, and that human-like characters appear transiently in fœtal stages of anthropoid apes, the further fact that many constant structural modifications of man's body are seen as occasional variations of the ape's body, all bear out Huxley's dictum that evolution tends to evolve along predetermined lines of modification. The machinery of evolution works out its untrammelled ends in the embryo and the fœtus, except in so far as that machinery can be injured or deflected by what may be termed poisons of the germ-plasm. It is clear, too, that if we are to cast man's horoscope we can read the omens only in the tendencies manifested in his embryonic and fœtal stages. We can alter man's future only in that limited way discovered by Darwin—by applying his principle of selection.

A Simile.

To make my meaning clear, let me borrow a simile from human affairs. Some thirty years ago, in the incipient stages which led to the modern development of the great motor-car industry, small workshops sprang up in almost every town and supplied a car of local design for local needs. The struggle for survival set in, and successful types, ousting local types, led to the formation of great firms which catered for the needs of continents. The workmen engaged and the types of car made became specialised and standardised. These great firms, we know, keep an eye on the market—benefit by experience—and modify their types to suit demand. Invention succeeds invention in their workshops. But in the factory where human types of body and mind are produced I am presuming there is no intelligence department. I am also presuming, as Huxley did, that the workmen—the cells of the embryo—employed in turning out new human machines, are specialised into vocational, hereditary castes—each caste turning out its work in a certain way—a way which ensures a functional result. I am presuming, too, that the workmen represented by the embryonic cells are co-ordinated in their toil by an elaborate system of intercommunication—already described—the system of hormones. All hands in the human factory are co-ordinated—not by orders from managers or foremen, but by a self-regulating system of hormone-control which works out functional ends automatically. Variations—useful adaptations—are produced by a bias which is inherent in the machinery of control. The mere fact that I have to resort to so crude a simile shows how ignorant we still are of the machinery of animal evolution.

Conclusion.

John Hunter gave utterance to an important truth when he said man's bony and vascular tissues retained the same automatic purposive behaviour as is manifested by the lowest forms of organised life, such as the hydra. In the formative period of the human embryo, and on the phase when adaptational contrivances are being worked out in its heart, brain, muscles, and skeleton, the embryonic cells retain many of the purposive, almost conscious, attributes possessed by primitive unicellular organisms. No doubt the behaviour of embryonic cells, as of the simplest protozoa, will prove to be reflex in nature—mere protoplasmic reactions to appropriate stimuli. In bringing about the collective reactions of embryonic tissues, which mould them to form structural adaptations, we may presume that hormones play a leading rôle. The hormone system, to give the results it does, must be framed upon a teleological basis.

If we would rightly understand the evolution of the machinery of adaptation, or, what is the same thing, the machinery of government, in the developing body of an animal, we shall do well, as Herbert Spencer suggested, to study the evolution of a people rising from savagedom to civilisation. In the earlier stages of the evolution of human society we see that the machinery of government is represented by the automatic working of a herd-instinct—an instinct tending in all its operations towards the preservation of the community. The instinct is biassed in the direction of producing functional or effective results. We have to study what, in our present ignorance, we must call the "herd-instincts" of the vast community of protoplasmic units embraced by the body of a human embryo, if we would understand how the structural contrivances of the human body have been evolved. I, for one, believe with Huxley that the government which rules within the body of the embryo proceeds along its way altogether uninfluenced by occurrences or experiences which affect the body or brain of the parent. In short, man has come by his great gifts—his brain, his upright posture, his strange foot and his nimble hand—not by any effort of his own, but, like a favoured child of the present day, has fallen heir to a fortune for which he has never laboured.

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The Life History of an α-Particle.[1]

By Sir ERNEST RUTHERFORD, F.R.S.

IN this lecture I propose to discuss some of the properties of the high-speed α-particle which is spontaneously ejected from radioactive substances. This flying atomic nucleus is not only the most energetic projectile known to us, but it is also an agent of great power in probing the structure of atoms, so that an account of the effects produced by it is of wide scientific interest.

It is now well established that the α-particle expelled from radioactive bodies is in all cases a helium atom, or, to be more precise, the nucleus of a helium atom of mass 4 carrying two positive charges of electricity. It is only when the expelled nucleus is stopped by its passage through matter that it captures the two negative electrons required to convert it into the neutral helium atom. It is natural to suppose that the helium nucleus, which is shot out at great speed from the heavy nucleus of a radioactive atom, formed part of its structure. For some reason, which is not as yet understood, occasionally one of the radioactive nuclei breaks up with explosive violence, ejecting the component helium nucleus with high velocity. It is probable that the α-particle in escaping from the radioactive nucleus acquires part of its great energy of motion in passing through the repulsive electric field surrounding the latter, but at present we do not know the nature of the forces which hold the complex nucleus together, or whether the α-particle is at rest or in orbital motion in the nuclear structure before instability sets in. We know, however, that there is a very wide range of stability exhibited by different radioactive elements. In a substance like radium A, the average life of the radioactive atom before ejection of an α-particle is about 4·3 minutes, for radium itself 2250 years, while in the case of a very slowly changing element like uranium the average life is of the order of 7000 million years.

It is known that the α-particles from a given element are all shot out with the same speed but that this speed varies from element to element. There is apparently a close connexion between the velocity of ejection of the α-particle and the average life of the parent element. The shorter the average life of the element, the swifter is the speed of expulsion. This interesting relation between the violence of the explosion and the average life of the element holds in the majority of cases, but it is difficult at present to be at all clear of its underlying meaning. Sir William Bragg long ago showed that the α-particle travels through matter nearly in a straight line, and has a definite range of travel in a substance. This is well illustrated by the tracks of α-particles obtained by Wilson's expansion method. The majority of the tracks are seen to be quite straight, apart from an occasional deflexion near the end of the path. At the end of the range the photographic and ionising effects of the α-particle apparently cease with great suddenness. On account of its great energy of motion, the individual α-particle can be detected by the scintillation it produces in crystalline zinc sulphide, by the effect on a photographic plate, and by special electrical methods, while the beautiful expansion method of Wilson shows the trail of each individual α-particle through the gas.

We are enabled, particularly by the scintillation method, to count the individual particles, and thus we have at our command a method of great delicacy for studying the effects produced by the passage of α-particles through matter. In travelling through a gas the α-particle passes through the outer electronic structure of a large number of atoms and liberates electrons, thus giving rise to an intense ionisation along the track. The ionisation increases to a maximum near the end of the path of the α-particle and then falls rapidly to zero.

A careful study has been made of the law of decrease of velocity of the α-particle in passing through matter by studying the deflexion in a magnetic field of a pencil of α-particles before and after its passage through a known thickness of matter. In most of these experiments we employ the α-particles of radium C, which have a range of about 7 cm. in air under ordinary conditions. The initial velocity V_0 of these particles is known to be 19,200 kilometres per second, and the reduction of velocity can readily be followed down to about 0·4 V_0. At this stage the emergent range of the α-particles is less than one centimetre, and measurements are difficult, owing to the fact that a beam of α-particles becomes heterogeneous and contains particles moving with different velocities.

[1] Discourse delivered at the Royal Institution on Friday, June 15.

For this reason the velocity of the α-particle cannot be followed with certainty below $0{\cdot}38\ V_0$. We must bear in mind that even at the lowest velocity at which it is possible to detect the α-particle by the scintillation or photographic method, it is still moving at a high speed compared with the positively charged particles generated in an ordinary discharge tube.

It is clear that ultimately the α-particle must be slowed down to such an extent that it captures electrons and becomes a neutral atom, but until recently no evidence of this process of capture of electrons had been obtained. G. H. Henderson (Proc. Roy. Soc. A, 102, p. 496, 1922) has recently added much to our knowledge of this subject by examining the deflexion of α-rays in a magnetic field in a very good vacuum. For the success of these experiments it is essential that the apparatus in which the deflexion is observed should be exhausted to a very low pressure, corresponding to that required for a good X-ray tube. The reason of this will be seen later. When a narrow pencil of α-rays was deflected in a magnetic field two bands were observed on the photographic plate, one the main band, due to ordinary α-particles carrying two positive charges, and another midway band which he supposed to consist of particles which had captured one electron, *i.e.* to singly charged helium atoms. At low velocities he also obtained evidence of the existence of neutral α-particles resulting from the capture of two electrons by the helium nucleus. In these experiments Henderson employed Schumann plates, where the film is so thin that low velocity particles produce as much or more photographic effect than the swifter particles.

I have repeated these experiments, by the scintillation method, and confirmed the deduction of Henderson. By observing the deflexion of the midway band in an electric as well as in a magnetic field I find there is no doubt the particles composing the midway band consist of particles of mass 4 and charge 1, *i.e.* to singly charged helium atoms which have the same speed as the doubly charged particles comprising the main band.

Some recent experiments have been made by me to throw light on the conditions under which the flying α-particles may gain or lose an electron. The general arrangement of the experiment is shown in Fig. 1. A fine platinum wire coated with radium B+C, by exposure to the emanation (radon) serves as a nearly homogeneous source of α-rays, since the α-particles are emitted only from the atoms of radium C, which are too few in number to form a film on the platinum of even one molecule thick. The α-rays from this source pass through a narrow slit about 0·3 mm. wide and fall on a screen of zinc sulphide. The distribution of α-particles on the screen is determined by the scintillation method in a dark room, using a microscope outside the box. The vessel containing the source and screen is completely exhausted by means of a Gaede and mercury diffusion pump, and if necessary the residual pressure can be measured by a Macleod gauge. The box is placed between the plane pole pieces of a large electromagnet so that the pencil of α-rays is bent in the direction shown in the figure. Usually the distance between the source and screen was 16 cm., with the slit midway. The whole path of the rays was exposed to a nearly uniform magnetic field and the deflexion of the pencil of rays was proportional to the strength of the magnetic field. Under normal experimental conditions the pencil of α-rays from the

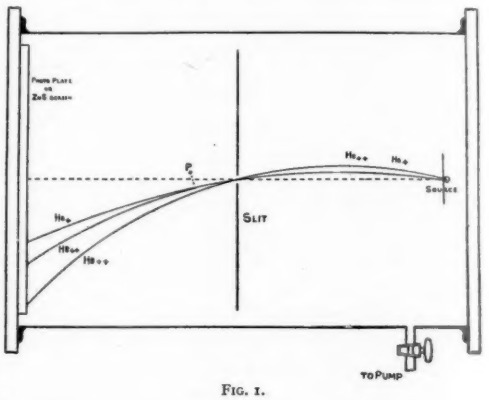


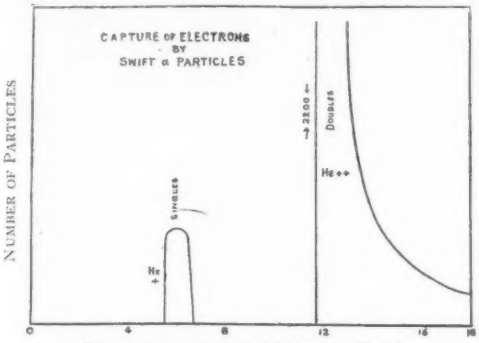
FIG. 1.

bare radium C wire was bent a distance on the screen of about 15 mm. from the zero position without field. The field of view of the microscope was sufficient to take in the depth of the whole pencil of α-rays without the field.

Special precautions were taken to prevent contamination of the screen by the escape of active matter from the wire in a low vacuum. It must be borne in mind that the type of wire source employed always introduces some heterogeneity in the beam of α-rays even from the uncovered source. This is due to the escape from the back of the wire of α-particles which are reduced in velocity in passing through the material. This effect is clearly manifest when the pencil of α-rays is deflected by a magnetic field; for in addition to the main band of α-rays there is always a distribution of particles extending beyond the main beam. The intensity of this heterogeneous beam at any point is generally less than one per cent. of the main beam and does not seriously interfere with the accuracy of the deductions discussed in this lecture.

In Figs. 2 and 3 are given illustrations of the distribution of singly and doubly charged α-particles

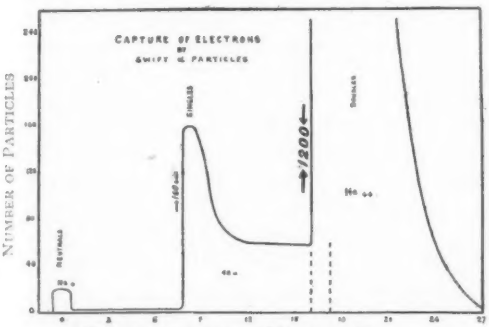
along the zinc sulphide screen. Fig. 2 shows the result when a thickness of mica corresponding in stopping power to 3·5 cm. of air is placed over the source. The main band, due to He_{++} particles, is sharply defined on the high velocity side, but there is evidence of some heterogeneity produced in the beam by its passage through the mica. As we should expect, the midway



DEFLEXION IN MM. BY MAGNETIC FIELD

FIG. 2.

band (He_+ particles) lies exactly between the zero position and the main band and contains only about 1/55 of the particles in the main beam. Fig. 3 shows the distribution when the thickness of mica is increased to correspond to a stopping power of about 6 cm. of air. Both the main and midway bands are no longer sharply defined as in the first case, but each

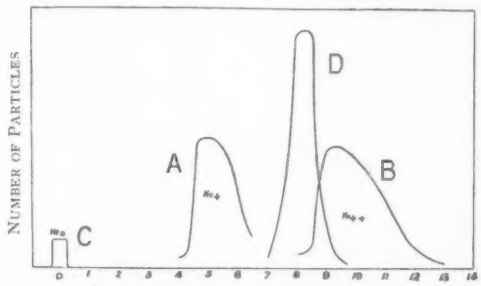


DEFLEXION IN MM. BY MAGNETIC FIELD

FIG. 3.

consists of particles with a considerable range of velocities. The relative number of He_+ and He_{++} particles is about 1/8 for the swifter particles, but this ratio increases with decreasing velocity. The midway band extends and joins the main band where it can no longer be followed. The brightness of the scintillations due to He_+ particles falls off obviously and continuously from A to B. At this stage, too, some neutral particles make their appearance. This is shown by the He_0 band, which is not deflected by a magnetic field, but its intensity is small compared with that of the midway band. There is also a sparse distribution of faint particles between the neutral and midway band, probably due in part to scattering of the α-particles by the edges of the slit and possibly in part due to recoil atoms of oxygen and other elements constituting the mica. The distribution of the charged and uncharged helium particles for a still lower velocity will be seen in curves A, B, Fig. 4, which will be referred to later. It is seen that the relative number of He_+ to He_{++} particles has increased; similarly, the relative number of neutral particles is much greater.

We may now consider the interpretation to be placed on these observations. It is clear that the particles emerging from the mica consist of doubly charged, singly charged, and neutral particles, but the relative number of these three types varies markedly with the stopping power of the mica plate. We may suppose that the α-particle in passing through the outer electron



DEFLEXION IN MM. BY MAGNETIC FIELD

FIG. 4.

structure of the atoms in its path occasionally removes and captures an electron. This electron falls into a stable orbit round the doubly charged helium nucleus and moves with it.

This singly charged atom will, however, have only a limited life, for in passing through other atoms the electron is knocked off and the singly charged α-particle reverts back to the doubly charged type. This process of removal is analogous to the ordinary process of ionisation where an electron is ejected from an atom by a collision with an α-particle; for as a singly charged particle can remove electrons from another atom, so there is a chance that the He_+ particle should lose its attendant electron. We may thus consider that two opposing processes are at work, one resulting in the capture of an electron and the other leading to its removal. From the data given later it will be seen that this process of capture and loss may repeat itself more than a thousand times in the flight of an α-particle, so that the average path travelled by an α-particle before capture of an electron or before loss of the captured electron is small compared with the total

distance of travel of the α-particle before it comes to rest. It is clear from this, for a given velocity of α-particle, that there must be a momentary equilibrium between the number of He_+ and He_{++} particles such that, on the average, the number of captures in a given small distance is equal to the number of losses.

It is very convenient to suppose that for a given velocity each He_{++} particle has a mean free path λ_1 cm. in the material before it captures an electron, and the He_+ particle a mean free path λ_2 cm. before it loses its attendant electron. No doubt some of the individual particles travel distances much shorter or longer than this mean distance before either capture or loss, but in considering a large number of particles we may suppose there is an average distance traversed before capture or loss, to be called the mean free path.

When N_1 He_{++} particles traverse a small distance dx of a material the number which capture electrons is $N_1 dx/\lambda_1$. If N_2 He_+ particles are present the number which lose an electron is $N_2 dx/\lambda_2$. But we have seen that when an equilibrium is set up, the number of captures in a given distance must equal the number of losses. Equating these two expressions, it is seen that $N_2/N_1 = \lambda_2/\lambda_1$, or, in other words, the relative number of He_+ to He_{++} particles is proportional to the ratio of the mean free path for loss to that for capture. Since by the scintillation method the ratio N_2/N_1 can be measured for any velocity, by using different thicknesses of absorber we can thus determine the ratio of the mean free paths for capture and loss for any velocity.

The actual value of the mean free path λ_2 of the He_+ particle before it loses its electron can be directly determined by experiment. Suppose the microscope is focussed on the midway band of Fig. 2 and the number of scintillations per minute observed in a good vacuum. If the pumps are shut off and a small quantity of air or other gas is introduced into the apparatus, the number of scintillations is found to diminish with increasing pressure of the air until the band has completely disappeared. This takes place at quite a low pressure of air, for example, for a pressure of about 1/4 mm. in the box.

The explanation of this result is obvious. The He_+ particles which escape from the mica occasionally collide with an atom of the gas in its path, and the electron which it captured in passing through the mica is removed. In such a case the He_+ becomes again an He_{++} particle, and the latter is twice as easily deflected in a magnetic field as the former. Suppose the collision occurs for the first time at the point P (Fig. 1). The particle after losing its electron travels along a new path shown in the figure, and the particle no longer strikes the part of the screen viewed by the microscope. It is found that the number of scintillations seen in the microscope falls off according to an exponential law as the pressure of the gas is raised. Such a result is to be expected, and from this data the average distance which the He_+ particle traverses before it loses its electron can be simply deduced. Certain small corrections are necessary to take into account the finite width of the band of scintillations as seen in the microscope, but we need not enter into details at this stage. It is convenient to express the mean free path λ_2 in air of the He_+ particles, not as the average length of path traversed in the rarefied gas before loss, but as the distance traversed in the same gas at standard pressure and temperature. For example, in a certain experiment, the mean free path in air of the particle was found to be 12 cm. at a pressure of 0·040 mm.; this corresponds to a mean free path of 0·0063 mm. at standard pressure and temperature.

In this way the mean free path in air before loss of an electron has been measured for different velocities, and it has been found over a considerable range that the mean free path varies directly as the velocity of the α-particle, so that the mean free path becomes shorter as the velocity of the α-particle diminishes. Since we may regard the loss of an electron from the singly charged particle as the result of a process of ionisation, such a relation is to be expected, and indeed, if we take into account the strong binding of a single electron by the He_{++} nucleus, the mean free path for loss is of the same order as that calculated from considerations of the number of ions per cm. produced by the α-particle in air and other gases. Comparisons have been made of the mean free path in air with that in hydrogen and helium. Its value is 4 to 5 times longer in hydrogen and more than 5 times longer in helium.

Now that the mean free path λ_2 is known, the value of λ_1 for capture can be deduced if the ratio N_2/N_1 is also known. A difficulty, however, arises at this point. In order to measure the ratio N_2/N_1 it is necessary that the active source should be covered with mica or other solid material. Gas cannot be used conveniently. It was found, however, that the ratio N_2/N_1 was the same within the limits of error whether the α-particles were reduced in velocity by passage through celluloid, mica, aluminium, or silver. For this purpose the mica was kept the same and a very thin sheet of the substance under examination spread over it. The thickness of the sheet was sufficient to set up a new equilibrium between the singly and doubly charged particles, but not sufficient to alter materially the velocity of the ionising rays.

Since the value of the ratio N_2/N_1 suffers no appreciable change for absorbers of such different atomic weights, we may safely conclude that the ratio for a

hypothetical sheet of solid air would be the same as for mica.

We have now all the data required to determine the values of λ_1 and λ_2 corresponding to α-particles of different velocities. The results are given in the following table for three different velocities. The mean free paths are expressed in terms of millimetres of air at standard pressure and temperature. V_0, the maximum velocity of the α-particles from radium C, is $1{\cdot}9 \times 10^9$ cm. per second.

Velocity V in terms of V_0.	$\lambda_2/\lambda_1 = N_2/N_1$ for Mica.	Mean Free Path λ_2 for Loss in Air.	Mean Free Path λ_1 for Capture in Air.
0·94	1/200	0·011 mm.	2·2 mm.
0·76	1/67	0·0078 mm.	0·52 mm.
0·47	1/7·5	0·0050 mm.	0·037 mm.

It has been seen that the mean free path for loss varies directly as the velocity, and thus only alters in a ratio of about 1 to 2 over the range of velocities given in the table. On the other hand, the ratio λ_2/λ_1 increases very rapidly with diminution of velocity varying approximately as V^{-5}. From this it follows that λ_1 varies as V^6, thus decreasing by a factor of 60 or more when the velocity is halved.

From these data and relations it can easily be calculated that the mean free path for capture should be equal to that for loss for a velocity about $0{\cdot}3\ V_0$, and for this speed the numbers of He_+ and He_{++} particles should be equal.

The actual value of the velocity for equality of the two types in a special experiment was found to be $0{\cdot}29\ V_0$, in good agreement with the calculated value. It is a difficult matter to determine the values of λ_1 and λ_2 for velocities less than $0{\cdot}3\ V_0$, for not only are the scintillations weak in intensity and difficult to count with accuracy, but also the issuing rays are very heterogeneous and no longer show well-defined edges on the high velocity side. It was, however, noted that the ratio N_2/N_1 rapidly increased below the velocity $0{\cdot}3\ V_0$.

We have so far dealt with the equilibrium between He_+ and He_{++} particles. It is clear, however, that similar considerations apply to the equilibrium between singly charged and neutral helium particles at low velocities of the α-particle. It was noted that the neutral particles appear prominently after the rays have passed through mica of 6 cm. stopping power, but no doubt they could be detected for still lower stopping power. These neutral particles, of course, produce scintillations, but of an intensity corresponding to an α-particle of low velocity. These neutral particles probably lose and regain an electron many times before they are stopped in the zinc sulphide or other absorbing material. This effect was shown by introducing gas at low pressure into the apparatus, when the scintillations due to the neutral particles diminished in number and ultimately vanished. The explanation of this is similar to that given for the disappearance of the He_+ band, for the neutral particles occasionally lose an electron in passing through the gas and are then deflected away from the zero position by the magnetic field.

It was estimated that the mean free path in air for conversion of neutral helium particles to singly charged particles was about 1/600 mm. No doubt this is an average for particles of very different velocities which may be present in the neutral band.

For the higher velocities we have to deal mainly with the interchange $He_{++} \rightleftarrows He_+$. For velocities less than $0{\cdot}5\ V_0$ the interchange $He_+ \rightleftarrows He_0$ also comes in and becomes all-important for velocities less than $0{\cdot}3\ V_0$. No doubt, as Henderson has shown, at still lower velocities most of the He_{++} particles disappear and the He_0 and He_+ particles predominate.

At these low velocities, counting scintillations becomes very difficult and uncertain, and the photographic method, as used by Henderson, is preferable. It will be a matter of very great interest to examine whether the relative numbers of the three types of particles alter when the α-particles are slowed down by passage through different materials. This side of the work is being attacked by Mr. Henderson in the University of Saskatchewan.

There is one very interesting point that may be considered here. It has been shown that these singly and doubly charged α-particles are always present after the α-rays have passed through mica or other absorber, but are there any singly charged particles present when α-particles escape from a wire coated with an infinitely thin deposit of active matter? This was first tested for a platinum wire coated with a deposit of radium B+C, by exposure to the radium emanation, when it was found that singly charged helium atoms were present in about the equilibrium ratio for this velocity. This was a rather surprising observation, but it was thought it might result from the fact that by the recoil from radium A the radium B particles penetrate some distance into the material of the wire. Under these conditions many of the α-particles expelled from radium C have to pass through a small but appreciable thickness of matter before escape from the wire and might thus capture electrons. This explanation seemed unlikely because the average distance penetrated by the recoil atom is only a minute fraction of the mean free path for capture at such high velocities of the α-particle. The experiment was tried with a nickel wire on which radium C had been deposited on

the surface by the well-known method of dipping the wire in a hot solution of radium C. In this case the difficulty due to recoil is absent, but the number of singly charged particles was the same as before.

It is very significant that the relative number of singly and doubly charged particles is about the equilibrium ratio to be expected when the wire, after being activated, is coated with an appreciable thickness of copper or other material. We can scarcely suppose that singly as well as doubly charged particles are actually liberated from the radioactive nucleus itself, for even if it be supposed that an α-particle with an attendant electron is expelled, the electron must be removed in escaping through the very powerful electric field close to the nucleus. It is much more probable that the doubly charged α-particle in passing through the dense distribution of electrons surrounding the radioactive nucleus occasionally captures an electron, and that the process of capture and loss goes on to some extent in escaping from the radioactive atom. This seems at first sight rather unlikely when we consider the relatively large number of atoms an α-particle ordinarily passes through before equilibrium between capture and loss is established, but it is well known that the chance of effective electronic collisions appears in general to be greater for a charged particle expelled from the central nucleus than for a similar particle passing from outside through the electronic distribution of an atom. It may be that those electrons, the orbital motion of which round the nucleus is comparable with the speed of the α-particle, are particularly effective in causing capture or loss.

So far we have dealt mainly with the distribution in a magnetic field of the particles in a vacuum after their escape from a mica surface. Some very interesting points arise when the distribution is examined in the presence of sufficient gas to cause a rapid interchange of capture and loss along the path of the α-particle in the gas. This is best illustrated by a diagram, Fig. 4, in which the results are given for α-particles escaping through mica with a maximum emergent range of about 4 or 5 millimetres in air. Curves A and B give approximately to scale the distribution of He_+ and He_{++} particles in a vacuum, while C gives the relative number of neutral particles under the experimental conditions. Suppose now sufficient air is introduced into the vessel to cause many captures along the gas but yet not enough to reduce seriously the velocity of the α-particles. The first salient fact to notice is that the distributions A, B, C vanish and there remains a distribution of particles (curve D) about midway between A and B. This band is narrower than either A or C, and its height at the maximum much greater than either. It is evident that the particles have been compressed into a band of much narrower width than the normal distribution in curve B.

This is exactly what we should expect to happen. The swifter particles present suffer less capture than the slow; consequently the average charge of the swifter α-particles along the gas is less than $2e$, and their deflexion is less than the swiftest particles shown in curve B. On the other hand, the slower α-particles have an average charge nearer $1e$ than $2e$ and are relatively still less deflected than the swifter particles. It is thus clear that the resulting distribution of particles with air inside the vessel will be concentrated over a much narrower width than the main band of He_{++} particles. From calculation based on the laws of capture and loss, the width of the band under the experimental conditions can be deduced and is found to be in good accord with experiment. It will be seen to be significant that similar results have been observed for hydrogen under corresponding conditions.

General Discussion of Results.

Attention may now be devoted to a consideration of the results so far obtained and the possibility of their explanation on present views. In the first place, it is important to emphasise the large number of capture and losses that occur during the flight of an α-particle from radium C. While the mean free path of the α-particle from radium C of 7 cm. range is about 3 mm. in air, its value rapidly decreases with lowering of the velocity of the α-particle and is probably about 0·0015 mm. for a velocity of $0{\cdot}3\ V_0$. It is not difficult to calculate that not far short of a thousand interchanges of charge occur during the path in air of a single particle between velocities V_0 and $0{\cdot}3\ V_0$. While the data so far obtained do not allow us to calculate the number of interchanges of charge that occur between velocities $0{\cdot}3\ V_0$ and 0, it seems probable that the number is considerably greater than a thousand. We have already pointed out that for low velocities the interchange $He_+ \rightleftarrows He_0$ predominates. When we consider the rapidity of interchange of charges of the α-particle at average velocities, it seems clear that we cannot expect to observe any appreciable difference in power of penetration between a beam of rays of the same velocity, whether consisting initially of singly or doubly charged particles. It is clear that a singly charged particle after penetrating a short distance is converted into a doubly charged particle and *vice versa*, and that the effects due to the two beams should be indistinguishable. Henderson tried such absorption experiments, using the photographic method, but with indefinite results.

When an α-particle captures an electron, the latter presumably falls into the same orbit round the helium nucleus as that which characterises an ionised helium atom, *i.e.* an atom which has lost one electron. When the α-particle with its attendant electron passes swiftly through the atoms of the gas in its path, it will not only ionise the gas but will also occasionally be itself ionised, *i.e.* will lose its attendant electron. When we take into account the strong binding of the first electron to the helium nucleus—ionisation potential about 54 volts—the mean free path for loss of the captured electrons in air is of the right order of magnitude to be expected from considerations based on the ionisation by the α-particle per unit path in air. While we can thus offer a quantitative explanation of the mean free path for loss observed experimentally, the inverse problem of the capture of an electron by the flying α-particle presents very great difficulties.

In the actual case, the α-particle is shot at high speed through gas molecules which for all practical purposes may be supposed to be at rest. For convenience of discussion, however, it is preferable to make an equivalent assumption, namely, that the α-particle is at rest and

the gas molecules stream by it with a velocity equal and opposite to that of the α-particle. Now the maximum velocity of an α-particle from radium C is equivalent to that gained by an electron in falling freely between a difference of potential of about 1000 volts; so that the electrons comprising the molecules of air or other gas have a velocity of translation numerically equal to this. For brevity, it is very convenient to speak of this velocity or energy as that due to a "1000-volt" electron.

When the electrons in an atom pass close to the α-particle, one of them may be removed from the parent atom by the collision, energy being required for this process. The ionisation potential for oxygen or nitrogen is about 17 volts, which is a very small quantity compared with the energy of translation of a 1000-volt electron.

If we consider the forces involved between an α-particle and moving electron as of the ordinary electrostatic type, the electron will describe a hyperbolic orbit round the nucleus, the angle of deflexion of the path of the electron resulting from the collision depending on the nearness of approach of the electron to the nucleus. On ordinary dynamics, the electron will never be captured in such a collision if there is no loss of energy by radiation. If capture for some reason results from the collision, it means that an amount of energy corresponding to at least a 1000-volt electron has in some way been got rid of. This loss of energy may be supposed to be due to some interaction between the α-particle and colliding nucleus with its attendant electrons, or to the loss of energy by radiation during the collision. The first supposition seems at first sight plausible, for we know that the innermost electrons of oxygen or nitrogen are strongly bound and require energy of the order of 500 volts to remove them from the atom. But there is one very strong and, it seems to me, insuperable objection to this view.

I have found that the deflexion in a magnetic field of a pencil of α-particles passing through a suitable pressure of hydrogen is similar to that shown in curve Fig. 4 for air. This shows that the α-particle passing through hydrogen captures electrons of energy about 120 volts to about the same degree as in air. Now we know that the electrons in the hydrogen atom or molecule are lightly bound, and an energy of not more than a 30-volt electron, suitably applied, would entirely separate the component nuclei and electrons in the hydrogen molecule. In the case of hydrogen, therefore, we cannot hope to account for the requisite loss of energy, which for the experiment considered is about 100 volts. If these experiments with hydrogen are correct, and are valid for all velocities of the α-particle, we are driven to conclude either, that some unknown factors are involved in the capture, or that the loss of energy of the electron must be ascribed to radiation. In such a case, capture of an electron may be regarded as the converse of the photo-electric effect, where radiation falls on matter and swift electrons are ejected from the matter. In the case under consideration, swift electrons are shot towards a charged nucleus and an occasional electron is captured with the emission of energy in the form of radiation. On such an hypothesis the radiation of energy from an α-particle passing through a gas due to the frequency of capture is very great, amounting to about 3 per cent. of the total energy of the α-particle. This seems to be an unexpectedly large amount, but cannot be ruled out as impossible in the present state of our knowledge.

In the discussion of this very thorny question, I have confined myself mainly to the case of capture by the swift α-particle, where the difficulties of explanation are much greater than for capture at slower velocities. Our information is at present too incomplete to give a decisive answer, but there seems to be no doubt that the unexpected frequency of capture of electrons by swift α-particles raises many new and interesting questions of the nature of the processes that can occur in collisions between electrons and matter.

I need scarcely say that the phenomena of capture and loss are not confined to the α-particle, but are shown by all charged atoms in swift motion through a gas, and were long ago observed in the case of positive rays. On account, however, of the high velocity of the α-particles and the ease of their individual detection, the process of capture and loss can be studied quantitatively under simpler and more definite conditions than in the case of the electric discharge through a gas at low pressure.

On this occasion I have devoted my attention to the most recent additions to our knowledge of the life history of the α-particle. This knowledge has been obtained from the study of the rapid interchange of charges when an α-particle passes through matter. I have only incidentally referred to the numerous collisions with electrons along the track of the α-particle which result in dense ionisation. I have omitted any consideration of those rare but interesting encounters in which an α-particle is deflected through a large angle by a close collision with a nucleus. I have omitted, too, the still rarer encounters which may result in a disintegration of an atomic nucleus like that of nitrogen or of aluminium. We have seen that an α-particle has an interesting history. Usually it is retained as an integral and orderly part of a radioactive nucleus for an interval of more than a thousand million years. Then follows a cataclysm in the radioactive nucleus; the α-particle gains its freedom and lives an independent life of about one hundred millionth of a second, during which all the incidents referred to in this lecture occur.

If we are dealing with a dense and compact uranium or thorium mineral, the α-particle after acquiring two electrons and becoming a neutral helium atom may be imprisoned in the mineral as long as the mineral exists. The occluded helium can be released from the mineral by the action of high temperature, and after removal of all other gases can be made to show its presence by the characteristic brilliant luminosity under the stimulus of the electric discharge. In the circumstances of such an experiment, only small quantities of helium are liberated. Large quantities of helium, sufficient to fill a large airship, have, however, been isolated from the natural gases which escape so freely from the earth in various parts of Canada and the United States. It is a striking fact that every single atom of this material has in all probability had the life history here described.

Addendum.[1]

It may be of interest to give here a brief review of some additional facts in connexion with the α-particle, brought to light in recent years. It has long been known that α-particles, although projected from the source at the same speed, travel unequal distances through a gas. For example, the maximum distance travelled by the α-particles from radium C in air is 7·04 cm. at 760 mm. and 15° C., the minimum distance is about 6·4 cm., and the mean distance about 6·8 cm. Some "straggling" of the α-particles is to be anticipated on general grounds, since the α-particle loses its energy mainly in liberating electrons from the atoms of matter in its path. On the laws of probability, one α-particle may meet more atoms and liberate more electrons than another, and thus lose energy at a faster rate. The amount of straggling observed is, however, much greater than can be accounted for in this way, and the occasional large deflexions of the α-particles due to nuclear collisions are so rare, except near the end of the range, that they do not seriously influence the final distribution.

Henderson has suggested that the property of an α-particle of capturing and losing electrons will introduce a new factor in causing straggling. No doubt this is the case, but the rates of capture and loss observed appear to be too rapid to account entirely for the discrepancy between theory and experiment. Another interesting suggestion has been made by Kapitza to account for the magnitude of this straggling. From the experiments of Chadwick and Bieler on the collision between α-particles and hydrogen nuclei, it has been deduced that the α-particle or helium nucleus has an asymmetrical field of force around it. This asymmetry of the electric field must become small at the distance of the orbits of the electrons in the neutral helium atom, but may be sufficient to fix the plane of the orbit of an electron relative to the axis of the helium nucleus.

Suppose that the α-particles liberated from a radioactive source have their axis orientated at random, and that the direction of the axis of each individual particle remains unchanged during its motion. In some cases, for example, the captured electron will describe an orbit of which the plane is nearly in the direction of motion of the α-particle; in other cases nearly perpendicular to it. It is to be expected, however, that the chance of losing the captured electron by collision will be greater in one case than the other; or, in other words, the mean free path of the singly charged α-particle before loss of its electron will be different in the two cases.

On this view, it is to be anticipated that one group of α-particles will lose energy faster than the other, and the ranges will be different. In order to test whether α-particles show the individual differences to be expected on this theory, Kapitza has photographed in the Cavendish Laboratory the tracks of a number of α-particles by the Wilson expansion method, using a strong magnetic field of about 70,000 Gauss, produced by a momentary current of great intensity. The magnetic field was sufficiently strong to cause a marked bending of the track of the α-particle. It was found that the curvature of the tracks at equal distances from the ends showed marked variations. Before any definite decision can be reached, a large number of tracks obtained in this way must be carefully measured up and allowance made for the sudden bends which occur due to a nuclear collision with the atoms of nitrogen or oxygen. The frequency of these bends near the end of the range complicates the interpretation of the apparent curvature which is measured. The experiments, which are still in progress, are difficult and require great technical skill, and it will be a matter of much interest if any definite asymmetry in the orbits of the singly charged α-particles can be established by this or other methods. If such an asymmetry exists, it must influence to a small extent the arrangement of the two electrons round the helium nucleus and possibly their spectrum.

During the past two years, Blackett, in the Cavendish Laboratory, has made a careful examination of the frequency of occurrence of sharp bends or forks in the tracks of α-particles near the end of their range in air and other gases. For this purpose, a simple form of Wilson expansion chamber, of the type designed by Shimizu, has been used, and each track has been photographed in two directions at right angles to each other to fix the angle of the forks in space. A large number of photographs have been taken, and the frequency of the forks has been examined in different gases, particularly in the last centimetre of the range of the α-particle. Assuming that these forks arise from nuclear collisions, it is possible to deduce from the experimental data the variation of velocity of the α-particle near the end of its range. It is known from the work of Geiger and Marsden that the maximum velocity v of the α-particles of emergent range R is given by $v^3 \propto R$, when R is not less than one centimetre. Blackett finds that this relation between velocity and range no longer holds near the end of the track but is replaced by a relation of the form $v^{1\cdot5} \propto R$.

In the course of these experiments a number of well-defined forks have been photographed in hydrogen, helium, air, and argon by Blackett, and also by Auger and Perrin in Paris. By measuring the angles between the original direction of the α-particle and the direction of the colliding particles after collision, the accuracy of the laws of impact can be directly tested. The results are found, within experimental error, to be in agreement with the view that the impacts are perfectly elastic and that the conservation of energy and of momentum hold in these nuclear collisions. Conversely, by assuming that the impacts are perfectly elastic, it is possible to deduce the mass of the recoil atom in terms of the α-particle of mass 4·00. For example, a fork in helium gave the mass of the recoil atom 4·03, and a fork in hydrogen gave the mass of the recoil atom 1·024. In a collision between the α-particle and a helium nucleus the angle between the forks should be exactly a right angle; the value measured was 89° 45′.

[1] This did not form part of the Royal Institution discourse, but it may usefully supplement one or two of the points surveyed in that lecture.

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The Electrical Structure of Matter.[1]

By Prof. Sir ERNEST RUTHERFORD, D.Sc., LL.D., Ph.D., F.R.S., President of the British Association.

IT was in 1896 that this Association last met in Liverpool, under the presidency of the late Lord Lister, that great pioneer in antiseptic surgery, whose memory is held in affectionate remembrance by all nations. His address, which dealt mainly with the history of the application of antiseptic methods to surgery and its connexion with the work of Pasteur, that prince of experimenters, whose birth has been so fittingly celebrated this year, gave us in a sense a completed page of brilliant scientific history. At the same time, in his opening remarks, Lister emphasised the importance of the discovery by Röntgen of a new type of radiation, the X-rays, which we now see marked the beginning of a new and fruitful era in another branch of science.

The visit to Liverpool in 1896 was for me a memorable occasion, for it was here that I first attended a meeting of this Association, and here that I read my first scientific paper. But of much more importance, it was here that I benefited by the opportunity, which these gatherings so amply afford, of meeting for the first time many of the distinguished scientific men of Great Britain and the foreign representatives of science who were the guests of this city on that occasion. The year 1896 has always seemed to me a memorable one for other reasons, for on looking back with some sense of perspective we cannot fail to recognise that the last Liverpool meeting marked the beginning of what has been aptly termed the heroic age of physical science. Never before in the history of physics has there been witnessed such a period of intense activity when discoveries of fundamental importance have followed one another with such bewildering rapidity.

The discovery of X-rays by Röntgen had been published to the world in 1895, while the discovery of the radioactivity of uranium by Becquerel was announced early in 1896. Even the most imaginative of our scientific men could never have dreamed at that time of the extension of our knowledge of the structure of matter that was to develop from these two fundamental discoveries, but in the records of the Liverpool meeting we see the dawning recognition of the possible consequences of the discovery of X-rays, not only in their application to medicine and surgery, but also as a new and powerful agent for attacking some of the fundamental problems of physics. The address of Sir J. J. Thomson, president of Section A, was devoted mainly to a discussion of the nature of the X-rays, and the remarkable properties induced in gases by the passage of X-rays through them—the beginning of a new and fruitful branch of study.

In applied physics, too, this year marked the beginning of another advance. In the discussion of a paper which I had the honour to read, on a new magnetic detector of electrical waves, the late Sir William Preece told the meeting of the successful transmission of signals for a few hundred yards by electric waves which had been made in England by a young Italian, G. Marconi. The first public demonstration of signalling for short distances by electric waves had been given by Sir Oliver Lodge at the Oxford Meeting of this Association in 1894. It is startling to recall the rapidity of the development from such small beginnings of the new method of wireless intercommunication over the greatest terrestrial distances. In the last few years this has been followed by the even more rapid growth of the allied subject of radiotelephony as a practical means of broadcasting speech and music to distances only limited by the power of the transmitting station. The rapidity of these technical advances is an illustration of the close interconnexion that must exist between pure and applied science if rapid and sure progress is to be made. The electrical engineer has been able to base his technical developments on the solid foundation of Maxwell's electromagnetic theory and its complete verification by the researches of Hertz, and also by the experiments of Sir Oliver Lodge in the University of Liverpool—a verification completed long before the practical possibilities of this new method of signalling had been generally recognised. The later advances in radiotelegraphy and radiotelephony have largely depended on the application of the results of fundamental researches on the properties of electrons, as illustrated in the use of the thermionic valve or electron tube which has proved such an invaluable agent for both the transmission and reception of electric waves.

It is of great interest to note that the benefits of this union of pure and applied research have not been one-sided. If the fundamental researches of the workers in pure science supply the foundations on which the applications are surely built, the successful practical application in turn quickens and extends the interest of the investigator in the fundamental problem, while the development of new methods and appliances required for technical purposes often provides the investigator with means of attacking still more difficult questions. This important reaction between pure and applied science can be illustrated in many branches of knowledge. It is particularly manifest in the industrial development of X-ray radiography for therapeutic and industrial purposes, where the development on a large scale of special X-ray tubes and improved methods of excitation has given the physicist much more efficient tools to carry out his researches on the nature of the rays themselves and on the structure of the atom. In this age no one can draw any sharp line of distinction

[1] Inaugural address delivered to the British Association at Liverpool on September 12.

between the importance of so-called pure and applied research. Both are equally essential to progress, and we cannot but recognise that without flourishing schools of research on fundamental matters in our universities and scientific institutions technical research must tend to wither. Fortunately there is little need to labour this point at the moment, for the importance of a training in pure research has been generally recognised. The Department of Scientific and Industrial Research has made a generous provision of grants to train qualified young men of promise in research methods in our scientific institutions, and has aided special fundamental researches which are clearly beyond the capacity of a laboratory to finance from its own funds. Those who have the responsibility of administering the grants in aid of research for both pure and applied science will need all their wisdom and experience to make a wise allocation of funds to secure the maximum of results for the minimum of expenditure. It is fatally easy to spend much money in a direct frontal attack on some technical problem of importance when the solution may depend on some addition to knowledge which can be gained in some other field of scientific inquiry possibly at a trifling cost. It is not in any sense my purpose to criticise those bodies which administer funds for fostering pure and applied research, but to emphasise how difficult it is to strike the correct balance between the expenditure on pure and applied science in order to achieve the best results in the long run.

It is my intention here to refer very briefly to some of the main features of that great advance in knowledge of the nature of electricity and matter which is one of the salient features of the interval since the last meeting of this Association in Liverpool.

In order to view the extensive territory which has been conquered by science in this interval, it is desirable to give a brief summary of the state of knowledge of the constitution of matter at the beginning of this epoch. Ever since its announcement by Dalton the atomic theory has steadily gained ground, and formed the philosophic basis for the explanation of the facts of chemical combination. In the early stages of its application to physics and chemistry it was unnecessary to have any detailed knowledge of the dimensions or structure of the atom. It was only necessary to assume that the atoms acted as individual units, and to know the relative masses of the atoms of the different elements. In the next stage, for example, in the kinetic theory of gases, it was possible to explain the main properties of gases by supposing that the atoms of the gas acted as minute perfectly elastic spheres. During this period, by the application of a variety of methods, many of which were due to Lord Kelvin, rough estimates had been obtained of the absolute dimensions and mass of the atoms. These brought out the minute size and mass of the atom and the enormous number of atoms necessary to produce a detectable effect in any kind of measurement. From this arose the general idea that the atomic theory must of necessity for ever remain unverifiable by direct experiment, and for this reason it was suggested by one school of thought that the atomic theory should be banished from the teaching of chemistry, and that the law of multiple proportions should be accepted as the ultimate fact of chemistry.

While the vaguest ideas were held as to the possible structure of atoms, there was a general belief among the more philosophically minded that the atoms of the elements could not be regarded as simple unconnected units. The periodic variations of the properties of the elements brought out by Mendeléeff were only explicable if atoms were similar structures in some way constructed of similar material. We shall see that the problem of the constitution of atoms is intimately connected with our conception of the nature of electricity. The wonderful success of the electromagnetic theory had concentrated attention on the medium or ether surrounding the conductor of electricity, and little attention had been paid to the actual carriers of the electric current itself. At the same time the idea was generally gaining ground that an explanation of the results of Faraday's experiments on electrolysis was only possible on the assumption that electricity, like matter, was atomic in nature. The name "electron" had even been given to this fundamental unit by Johnstone Stoney, and its magnitude roughly estimated, but the full recognition of the significance and importance of this conception belongs to the new epoch.

For the clarifying of these somewhat vague ideas, the proof in 1897 of the independent existence of the electron as a mobile electrified unit, of mass minute compared with that of the lightest atom, was of extraordinary importance. It was soon seen that the electron must be of a constituent of all the atoms of matter, and that optical spectra had their origin in their vibrations. The discovery of the electron and the proof of its liberation by a variety of methods from all the atoms of matter was of the utmost significance, for it strengthened the view that the electron was probably the common unit in the structure of atoms which the periodic variation of the chemical properties had indicated. It gave for the first time some hope of the success of an attack on that most fundamental of all problems—the detailed structure of the atom. In the early development of this subject science owes much to the work of Sir J. J. Thomson, both for the boldness of his ideas and for his ingenuity in developing methods for estimating the number of electrons in the atom, and in probing its structure. He early took the view that the atom must be an electrical structure, held together by electrical forces, and showed in a general way lines of possible explanation of the variation of physical and chemical properties of the elements, exemplified in the periodic law.

In the meantime our whole conception of the atom and of the magnitude of the forces which held it together were revolutionised by the study of radioactivity. The discovery of radium was a great step in advance, for it provided the experimenter with powerful sources of radiation specially suitable for examining the nature of the characteristic radiations which are emitted by the radioactive bodies in general. It was soon shown that the atoms of radioactive matter were undergoing spontaneous transformation, and that the characteristic radiations emitted, namely, the α-, β-, and γ-rays, were an accompaniment and consequence of these atomic explosions. The wonderful succession of changes that occur in uranium and thorium, more

than thirty in number, was soon disclosed and simply interpreted on the transformation theory. The radioactive elements provide us for the first time with a glimpse into Nature's laboratory, and allow us to watch and study, but not to control, the changes that have their origin in the heart of the radioactive atoms. These atomic explosions involve energies which are gigantic compared with those involved in any ordinary physical or chemical process. In the majority of cases an α-particle is expelled at high speed, but in others a swift electron is ejected often accompanied by a γ-ray, which is a very penetrating X-ray of high frequency. The proof that the α-particle is a charged helium atom for the first time disclosed the importance of helium as one of the units in the structure of the radioactive atoms, and probably also in that of the atoms of most of the ordinary elements. Not only then have the radioactive elements had the greatest direct influence on natural philosophy, but in subsidiary ways they have provided us with experimental methods of almost equal importance. The use of α-particles as projectiles with which to explore the interior of the atom has definitely exhibited its nuclear structure, has led to artificial disintegration of certain light atoms, and promises to yield more information yet as to the actual structure of the nucleus itself.

The influence of radioactivity has also extended to yet another field of study of fascinating interest. We have seen that the first rough estimates of the size and mass of the atom gave little hope that we could detect the effect of a single atom. The discovery that the radioactive bodies expel actual charged atoms of helium with enormous energy altered this aspect of the problem. The energy associated with a single α-particle is so great that it can readily be detected by a variety of methods. Each α-particle, as Sir William Crookes first showed, produces a flash of light easily visible in a dark room when it falls on a screen coated with crystals of zinc sulphide. This scintillation method of counting individual particles has proved invaluable in many researches, for it gives us a method of unequalled delicacy for studying the effects of single atoms. The α-particle can also be detected electrically or photographically, but the most powerful and beautiful of all methods is that perfected by Mr. C. T. R. Wilson for observing the track through a gas, not of an α-particle alone, but of any type of penetrating radiation which produces ions or of electrified particles along its path. The method is comparatively simple, depending on the fact, first discovered by him, that if a gas saturated with moisture is suddenly cooled each of the ions produced by the radiation becomes the nucleus of a visible drop of water. The water-drops along the track of the α-particle are clearly visible to the eye, and can be recorded photographically. These beautiful photographs of the effect produced by single atoms or single electrons appeal, I think, greatly to all scientific men. They not only afford convincing evidence of the discrete nature of these particles, but also give us new courage and confidence that the scientific methods of experiment and deduction are to be relied upon in this field of inquiry; for many of the essential points brought out so clearly and concretely in these photographs were correctly deduced long before such confirmatory photographs were available. At the same time, a minute study of the detail disclosed in these photographs gives us most valuable information and new clues on many recondite effects produced by the passage through matter of these flying projectiles and penetrating radiations.

In the meantime a number of new methods had been devised to fix with some accuracy the mass of the individual atom and the number in any given quantity of matter. The concordant results obtained by widely different physical principles gave great confidence in the correctness of the atomic idea of matter. The method found capable of most accuracy depends on the definite proof of the atomic nature of electricity and the exact valuation of this fundamental unit of charge. We have seen that it was early surmised that electricity was atomic in nature. This view was confirmed and extended by a study of the charges carried by electrons, α-particles, and the ions produced in gases by X-rays and the rays from radioactive matter. It was first shown by Townsend that the positive or negative charge carried by an ion in gases was invariably equal to the charge carried by the hydrogen ion in the electrolysis of water, which we have seen was assumed, and assumed correctly, by Johnstone Stoney to be the fundamental unit of charge. Various methods were devised to measure the magnitude of this fundamental unit; the best known and most accurate is Millikan's, which depends on comparing the pull of an electric field on a charged droplet of oil or mercury with the weight of the drop. His experiments gave a most convincing proof of the correctness of the electronic theory, and gave a measure of this unit, the most fundamental of all physical units, with an accuracy of about one in a thousand. Knowing this value, we can by the aid of electrochemical data easily deduce the mass of the individual atoms and the number of molecules in a cubic centimetre of any gas with an accuracy of possibly one in a thousand, but certainly better than one in a hundred. When we consider the minuteness of the unit of electricity and of the mass of the atom, this experimental achievement is one of the most notable even in an era of great advances.

The idea of the atomic nature of electricity is very closely connected with the attack on the problem of the structure of the atom. If the atom is an electrical structure it can only contain an integral number of charged units, and, since it is ordinarily neutral, the number of units of positive charge must equal the number of negative. One of the main difficulties in this problem has been the uncertainty as to the relative part played by positive and negative electricity in the structure of the atom. We know that the electron has a negative charge of one fundamental unit, while the charged hydrogen atom, whether in electrolysis or in the electric discharge, has a charge of one positive unit. But the mass of the electron is only 1/1840 of the mass of the hydrogen atom, and though an extensive search has been made, not the slightest evidence has been found of the existence of a positive electron of small mass like the negative. In no case has a positive charge been found associated with a mass less than that of the charged atom of hydrogen. This difference between positive and negative electricity is at first sight very surprising, but the deeper we pursue our inquiries the more this fundamental difference

between the units of positive and negative electricity is emphasised. In fact, as we shall see later, the atoms are quite unsymmetrical structures with regard to the positive and negative units contained in them, and indeed it seems certain that if there were not this difference in mass between the two units, matter, as we know it, could not exist.

It is natural to inquire what explanation can be given of this striking difference in mass of the two units. I think all scientific men are convinced that the small mass of the negative electron is to be associated entirely with the energy of its electrical structure, so that the electron may be regarded as a disembodied atom of negative electricity. We know that an electron in motion, in addition to possessing an electric field, also generates a magnetic field around it, and energy in the electromagnetic form is stored in the medium and moves with it. This gives the electron an apparent or electrical mass, which, while nearly constant for slow speeds, increases rapidly as its velocity approaches that of light. This increase of mass is in good accord with calculation, whether based on the ordinary electrical theory or on the theory of relativity. Now we know that the hydrogen atom is the lightest of all atoms, and is presumably the simplest in structure, and that the charged hydrogen atom, which we shall see is to be regarded as the hydrogen nucleus, carries a unit positive charge. It is thus natural to suppose that the hydrogen nucleus is the atom of positive electricity, or positive electron, analogous to the negative electron, but differing from it in mass. Electrical theory shows that the mass of a given charge of electricity increases with the concentration, and the greater mass of the hydrogen nucleus would be accounted for if its size were much smaller than that of the electron. Such a conclusion is supported by evidence obtained from the study of the close collisions of α-particles with hydrogen nuclei. It is found that the hydrogen nucleus must be of minute size, of radius less than the electron, which is usually supposed to be about 10^{-13} cm.; also the experimental evidence is not inconsistent with the view that the hydrogen nucleus may actually be much smaller than the electron. While the greater mass of the positive atom of electricity may be explained in this way, we are still left with the enigma why the two units of electricity should differ so markedly in this respect. In the present state of our knowledge it does not seem possible to push this inquiry further, or to discuss the problem of the relation of these two units.

We shall see that there is the strongest evidence that the atoms of matter are built up of these two electrical units, namely the electron and the hydrogen nucleus or proton, as it is usually called when it forms part of the structure of any atom. It is probable that these two are the fundamental and indivisible units which build up our universe, but we may reserve in our mind the possibility that further inquiry may some day show that these units are complex, and divisible into even more fundamental entities. On the views we have outlined, the mass of the atom is the sum of the electrical masses of the individual charged units composing its structure, and there is no need to assume that any other kind of mass exists. At the same time, it is to be borne in mind that the actual mass of an atom may be somewhat less than the sum of the masses of component positive and negative electrons when in the free state. On account of the very close proximity of the charged units in the nucleus of an atom, and the consequent disturbance of the electric and magnetic fields surrounding them, such a decrease of mass is to be anticipated on general theoretical grounds.

We must now look back again to the earlier stages of the present epoch in order to trace the development of our ideas on the detailed structure of the atom. That electrons as such were important constituents was clear by 1900, but little real progress followed until the part played by the positive charges was made clear. New light was thrown on this subject by examining the deviation of α-particles when they passed through the atoms of matter. It was found that occasionally a swift α-particle was deflected from its rectilinear path through more than a right angle by an encounter with a single atom. In such a collision the laws of dynamics ordinarily apply, and the relation between the velocities of the colliding atoms before and after collision are exactly the same as if the two colliding particles are regarded as perfectly elastic spheres of minute dimensions. It must, however, be borne in mind that in these atomic collisions there is no question of mechanical impacts such as we observe with ordinary matter. The reaction between the two particles occurs through the intermediary of the powerful electric fields that surround them. Beautiful photographs illustrating the accuracy of these laws of collision between an α-particle and an atom have been obtained by Messrs. Wilson, Blackett, and others, while Mr. Wilson has recently obtained many striking illustrations of collisions between two electrons. Remembering the great kinetic energy of the α-particle, its deflexion through a large angle in a single atomic encounter shows clearly that very intense deflecting forces exist inside the atom. It seemed clear that electric fields of the required magnitude could be obtained only if the main charge of the atom were concentrated in a minute nucleus. From this arose the conception of the nuclear atom, now so well known, in which the heart of the atom is supposed to consist of a minute but massive nucleus, carrying a positive charge of electricity, and surrounded at a distance by the requisite number of electrons to form a neutral atom.

A detailed study of the scattering of α-particles at different angles, by Geiger and Marsden, showed that the results were in close accord with this theory, and that the intense electric forces near the nucleus varied according to the ordinary inverse square law. In addition, the experiments allowed us to fix an upper limit for the dimensions of the nucleus. For a heavy atom like that of gold the radius of the nucleus, if supposed to be spherical, was less than one-thousandth of the radius of the complete atom surrounded by its electrons, and certainly less than 4×10^{-12} cm. All the atoms were found to show this nuclear structure, and an approximate estimate was made of the nuclear charge of different atoms. This type of nuclear atom, based on direct experimental evidence, possesses some very simple properties. It is obvious that the number of units of resultant positive charge in the nucleus

fixes the number of the outer planetary electrons in the neutral atom. In addition, since these outer electrons are in some way held in equilibrium by the attractive forces from the nucleus, and, since we are confident from general physical and chemical evidence that all atoms of any one element are identical in their external structure, it is clear that their arrangement and motion must be governed entirely by the magnitude of the nuclear charge. Since the ordinary chemical and physical properties are to be ascribed mainly to the configuration and motion of the outer electrons, it follows that the properties of an atom are defined by a whole number representing its nuclear charge. It thus becomes of great importance to determine the value of this nuclear charge for the atoms of all the elements.

Data obtained from the scattering of α-particles, and also from the scattering of X-rays by light elements, indicated that the nuclear charge of an element was numerically equal to about half the atomic weight in terms of hydrogen. It was fairly clear from general evidence that the hydrogen nucleus had a charge one, and the helium nucleus (the α-particle) a charge two. At this stage another discovery of great importance provided a powerful method of attack on this problem. The investigation by Laue on the diffraction of X-rays by crystals had shown definitely that X-rays were electromagnetic waves of much shorter wavelength than light, and the experiments of Sir William Bragg and W. L. Bragg had provided simple methods for studying the spectra of a beam of X-rays. It was found that the spectrum in general shows a continuous background on which is superimposed a spectrum of bright lines. At this stage H. G. J. Moseley began a research with the intention of deciding whether the properties of an element depended on its nuclear charge rather than on its atomic weight as ordinarily supposed. For this purpose the X-ray spectra emitted by a number of elements were examined and found to be all similar in type. The frequency of a given line was found to vary very nearly as the square of a whole number which varied by unity in passing from one element to the next. Moseley identified this whole number with the atomic or ordinal number of the elements when arranged in increasing order of atomic weight, allowance being made for the known anomalies in the periodic table and for certain gaps corresponding to possible but missing elements. He concluded that the atomic number of an element was a measure of its nuclear charge, and the correctness of this deduction has been recently verified by Chadwick by direct experiments on the scattering of α-particles. Moseley's discovery is of fundamental importance, for it not only fixes the number of electrons in all the atoms, but also shows conclusively that the properties of an atom, as had been surmised, are determined not by its atomic weight but by its nuclear charge. A relation of unexpected simplicity is thus found to hold between the elements. No one could have anticipated that with few exceptions all atomic numbers between hydrogen 1, and uranium 92, would correspond to known elements. The great power of Moseley's law in fixing the atomic number of an element is well illustrated by the recent discovery by Coster and Hevesy in Copenhagen of the missing element of atomic number 72, which they have named "hafnium."

Once the salient features of the structure of atoms have been fixed and the number of electrons known, the further study of the structure of the atom falls naturally into two great divisions: one, the arrangement of the outer electrons which controls the main physical and chemical properties of an element, and the other, the structure of the nucleus on which the mass and radioactivity of the atom depend. On the nuclear theory the hydrogen atom is of extreme simplicity, consisting of a singly-charged positive nucleus with only one attendant electron. The position and motions of the single electron must account for the complicated optical spectrum, and whatever physical and chemical properties are to be attributed to the hydrogen atom. The first definite attack on the problem of the electronic structure of the atom was made by Niels Bohr. He saw clearly that, if this simple constitution was assumed, it is impossible to account for the spectrum of hydrogen on the classical electrical theories, but that a radical departure from existing views was necessary. For this purpose he applied to the atom the essential ideas of the quantum theory which had been developed by Planck for other purposes, and had been found of great service in explaining many fundamental difficulties in other branches of science. On Planck's theory, radiation is emitted in definite units or quanta, in which the energy E of a radiation is equal to $h\nu$ where ν is the frequency of the radiation measured by the ordinary methods and h a universal constant. This quantum of radiation is not a definite fixed unit like the atom of electricity, for its magnitude depends on the frequency of the radiation. For example, the energy of a quantum is small for visible light, but becomes large for radiation of high frequency corresponding to the X-rays or the γ-rays from radium.

Time does not allow me to discuss the underlying meaning of the quantum theory or the difficulties connected with it. Certain aspects of the difficulties were discussed in the presidential address before this Association by Sir Oliver Lodge at Birmingham in 1913. It suffices to say that this theory has proved of great value in several branches of science, and is supported by a large mass of direct experimental evidence.

In applying the quantum theory to the structure of the hydrogen atom Bohr supposed that the single electron could move in a number of stable orbits, controlled by the attractive force of the nucleus, without losing energy by radiation. The position and character of these orbits were defined by certain quantum relations depending on one or more whole numbers. It was assumed that radiation was only emitted when the electron for some reason was transferred from one stable orbit to another of lower energy. In such a case it was supposed that a homogeneous radiation was emitted of frequency ν determined by the quantum relation $E = h\nu$ where E was the difference of the energy of the electron in the two orbits. Some of these possible orbits are circular, others elliptical, with the nucleus as a focus, while if the change of mass of the electron with velocity is taken into account the orbits, as Sommerfeld showed, depend on two quantum numbers, and are not closed, but consist of a nearly elliptical orbit slowly rotating round the nucleus. In this way it is possible not only to account for the series relations between the bright lines of the hydrogen spectrum, but also to explain the

fine structure of the lines and the very complicated changes observed when the radiating atoms are exposed in a strong magnetic or electric field. Under ordinary conditions the electron in the hydrogen atom rotates in a circular orbit close to the nucleus, but if the atoms are excited by an electric discharge or other suitable method, the electron may be displaced and occupy any one of the stable positions specified by the theory. In a radiating gas giving the complete hydrogen spectrum there will be present many different kinds of hydrogen atoms, in each of which the electron describes one of the possible orbits specified by the theory. On this view it is seen that the variety of modes of vibration of the hydrogen atom is ascribed, not to complexity of the structure of the atom, but to the variety of stable orbits which an electron may occupy relative to the nucleus. This novel theory of the origin of spectra has been developed so as to apply not to hydrogen alone but to all the elements, and has been instrumental in throwing a flood of light on the relations and origin of their spectra, both X-ray and optical. The information thus gained has been applied by Bohr to determine the distribution of the electrons round the nucleus of any atom. The problem is obviously much less complicated for hydrogen than for a heavy atom, where each of the large number of electrons present acts on the other, and where the orbits described are much more intricate than the orbit of the single electron in hydrogen. Notwithstanding the great difficulties of such a complicated system of electrons in motion, it has been possible to fix the quantum numbers that characterise the motion of each electron, and to form at any rate a rough idea of the character of the orbit.

These planetary electrons divide themselves up into groups, according as their orbits are characterised by one or more equal quantum numbers. Without going into detail a few examples may be given to illustrate the conclusions which have been reached. As we have seen, the first element, hydrogen, has a nuclear charge of 1 and 1 electron; the second, helium, has a charge 2 and 2 electrons, moving in coupled orbits on the detailed nature of which there is still some uncertainty. These two electrons form a definite group, known as the K group, which is common to all the elements except hydrogen. For increasing nuclear charge the K group of electrons retains its characteristics, but moves with increasing speed, and approaches closer to the nucleus. As we pass from helium of atomic number 2 to neon, number 10, a new group of electrons is added consisting of two sub-groups, each of four electrons, together called the L group. This L group appears in all atoms of higher atomic number, and, as in the case of the K group, the speed of motion of the electrons increases, and the size of their orbits diminishes with the atomic number. When once the L group has been completed a new and still more complicated M group of electrons begins forming outside it, and a similar process goes on until uranium, which has the highest atomic number, is reached.

It may be of interest to try to visualise the conception of the atom we have so far reached by taking for illustration the heaviest atom, uranium. At the centre of the atom is a minute nucleus surrounded by a swirling group of 92 electrons, all in motion in definite orbits, and occupying but by no means filling a volume very large compared with that of the nucleus. Some of the electrons describe nearly circular orbits round the nucleus; others, orbits of a more elliptical shape with axes rotating rapidly round the nucleus. The motion of the electrons in the different groups is not necessarily confined to a definite region of the atom, but the electrons of one group may penetrate deeply into the region mainly occupied by another group, thus giving a type of inter-connexion or coupling between the various groups. The maximum speed of any electron depends on the closeness of the approach to the nucleus, but the outermost electron will have a minimum speed of more than 1000 kilometres per second, while the innermost K electrons have an average speed of more than 150,000 kilometres per second, or half the speed of light. When we visualise the extraordinary complexity of the electronic system we may be surprised that it has been possible to find any order in the apparent medley of motions.

In reaching these conclusions, which we owe largely to Prof. Bohr and his co-workers, every available kind of data about the different atoms has been taken into consideration. A study of the X-ray spectra, in particular, affords information of great value as to the arrangement of the various groups in the atom, while the optical spectrum and general chemical properties are of great importance in deciding the arrangements of the superficial electrons. While the solution of the grouping of the electrons proposed by Bohr has been assisted by considerations of this kind, it is not empirical in character, but has been largely based on general theoretical considerations of the orbits of electrons that are physically possible on the generalised quantum theory. The real problem involved may be illustrated in the following way. Suppose the gold nucleus be in some way stripped of its attendant seventy-nine electrons and that the atom is reconstituted by the successive addition of electrons one by one. According to Bohr, the atom will be reorganised in one way only, and one group after another will successively form and be filled up in the manner outlined. The nucleus atom has often been likened to a solar system where the sun corresponds to the nucleus and the planets to the electrons. The analogy, however, must not be pressed too far. Suppose, for example, we imagined that some large and swift celestial visitor traverses and escapes from our solar system without any catastrophe to itself or the planets. There will inevitably result permanent changes in the lengths of the month and year, and our system will never return to its original state. Contrast this with the effect of shooting an electron or α-particle through the electronic structure of the atom. The motion of many of the electrons will be disturbed by its passage, and in special cases an electron may be removed from its orbit and hurled out of its atomic system. In a short time another electron will fall into the vacant place from one of the outer groups, and this vacant place in turn will be filled up, and so on until the atom is again reorganised. In all cases the final state of the electronic system is the same as in the beginning. This illustration also serves to indicate the origin of the X-rays excited in the atom, for these arise in the process of re-formation of an atom from which an electron has been ejected, and the radiation

of highest frequency arises when the electron is removed from the K group.

It is possibly too soon to express a final opinion on the accuracy of this theory which defines the outer structure of the atom, but there can be no doubt that it constitutes a great advance. Not only does it offer a general explanation of the optical and X-ray spectra of the atom, but it accounts in detail for many of the most characteristic features of the periodic law of Mendeléeff. It gives us for the first time a clear idea of the reason for the appearance in the family of elements of groups of consecutive elements with similar chemical properties, such as the groups analogous to the iron group and the unique group of rare earths. The theory of Bohr, like all living theories, has not only correlated a multitude of isolated facts known about the atom, but has shown its power to predict new relations which can be verified by experiment. For example, the theory predicted the relations which must subsist between the Rydberg constants of the arc and spark spectra, and generally between all the successive optical spectra of an element, a prediction so strikingly confirmed by Paschen's work on the spectrum of doubly ionised aluminium and Fowler's work on the spectrum of trebly ionised silicon. Finally, it predicted with such great confidence the chemical properties of the missing element, number 72, that it gave the necessary incentive for its recent discovery.

While the progress of our knowledge of the outer structure of atoms has been much more rapid than could have been anticipated, we clearly see that only a beginning has been made on this great problem, and that an enormous amount of work is still required before we can hope to form anything like a complete picture even of the outer structure of the atom. We may be confident that the main features of the structure are clear, but in a problem of such great complexity progress in detail must of necessity be difficult and slow.

We have not so far referred to the very difficult question of the explanation on this theory of the chemical combination of atoms. In fact, as yet the theory has scarcely concerned itself with molecular structure. On the chemical side, however, certain advances have already been made, notably by G. N. Lewis, Kossel, and Langmuir, in the interpretation of the chemical evidence by the idea of shared electrons, which play a part in the electronic structure of two combined atoms. There can be little doubt that the next decade will see an intensified attack by physicists and chemists on this very important but undoubtedly very complicated question.

Before leaving this subject, it may be of interest to refer to certain points in Bohr's theory of a more philosophical nature. It is seen that the orbits and energies of the various groups of electrons can be specified by certain quantum numbers, and the nature of the radiation associated with a change of orbit can be defined. But at the same time we cannot explain why these orbits are alone permissible under normal conditions, or understand the mechanism by which radiation is emitted. It may be quite possible to formulate accurately the energy relation of the electrons in the atom on a simple theory, and to explain in considerable detail all the properties of an atom, without any clear understanding of the underlying processes which lead to these results. It is natural to hope that with advance of knowledge we may be able to grasp the details of the process which leads to the emission of radiation, and to understand why the orbits of the electrons in the atom are defined by the quantum relations. Some, however, are inclined to take the view that in the present state of knowledge it may be quite impossible in the nature of things to form that detailed picture in space and time of successive events that we have been accustomed to consider as so important a part of a complete theory. The atom is naturally the most fundamental structure presented to us. Its properties must explain the properties of all more complicated structures, including matter in bulk, but we may not, therefore, be justified in expecting that its processes can be explained in terms of concepts derived entirely from a study of molar properties. The atomic processes involved may be so fundamental that a complete understanding may be denied us. It is early yet to be pessimistic on this question, for we may hope that our difficulties may any day be resolved by further discoveries.

We must now turn our attention to that new and comparatively unexplored territory, the nucleus of the atom. In a discussion on the structure of the atom ten years ago, in answer to a question on the structure of the nucleus, I was rash enough to say that it was a problem that might well be left to the next generation, for at that time there seemed to be few obvious methods of attack to throw light on its constitution. While much more progress has been made than appeared possible at that time, the problem of the structure of the nucleus is inherently more difficult than the allied problem already considered of the structure of the outer atom, where we have a wealth of information obtained from the study of light and X-ray spectra and from the chemical properties to test the accuracy of our theories.

In the case of the nucleus, we know its resultant charge, fixed by Moseley's law, and its mass, which is very nearly equal to the mass of the whole atom, since the mass of the planetary electrons is relatively very small and may for most purposes be neglected. We know that the nucleus is of size minute compared with that of the whole atom, and can with some confidence set a maximum limit to its size. The study of radioactive bodies has provided us with very valuable information on the structure of the nucleus, for we know that the α- and β-particles must be expelled from it, and there is strong evidence that the very penetrating γ-rays represent modes of vibration of the electrons contained in its structure. In the long series of transformations which occur in the uranium atom, eight α-particles are emitted and six electrons, and it seems clear that the nucleus of a heavy atom is built up, in part at least, of helium nuclei and electrons. It is natural to suppose that many of the ordinary stable atoms are constituted in a similar way. It is a matter of remark that no indication has been obtained that the lightest nucleus, namely, that of hydrogen, is liberated in these transformations, where the processes occurring are of so fundamental a character. At the same time, it is evident that the hydrogen nucleus must be a unit in the structure of some atoms,

and this has been confirmed by direct experiment. Dr. Chadwick and I have observed that swift hydrogen nuclei are released from the elements boron, nitrogen, fluorine, sodium, aluminium, and phosphorus when they are bombarded by swift α-particles, and there is little room for doubt that these hydrogen nuclei form an essential part of the nuclear structure. The speed of ejection of these nuclei depends on the velocity of the α-particle and on the element bombarded. It is of interest to note that the hydrogen nuclei are liberated in all directions, but the speed in the backward direction is always somewhat less than in the direction of the α-particle. Such a result receives a simple explanation if we suppose that the hydrogen nuclei are not built into the main nucleus but exist as satellites probably in motion round a central core. There can be no doubt that bombardment by α-particles has effected a veritable disintegration of the nuclei of this group of elements. It is significant that the liberation of hydrogen nuclei only occurs in elements of odd atomic number, namely, 5, 7, 9, 11, 13, 15, the elements of even number appearing quite unaffected. For a collision of an α-particle to be effective, it must either pass close to the nucleus or actually penetrate its structure. The chance of this is excessively small on account of the minute size of the nucleus. For example, although each individual α-particle will pass through the outer structure of more than 100,000 atoms of aluminium in its path, it is only about one α-particle in a million that gets close enough to the nucleus to effect the liberation of its hydrogen satellite.

This artificial disintegration of elements by α-particles takes place only on a minute scale, and its observation has only been possible by the counting of individual swift hydrogen nuclei by the scintillations they produce in zinc sulphide.

These experiments suggest that the hydrogen nucleus or proton must be one of the fundamental units which build up a nucleus, and it seems highly probable that the helium nucleus is a secondary building unit composed of the very close union of four protons and two electrons. The view that the nuclei of all atoms are ultimately built up of protons of mass nearly one and of electrons has been strongly supported and extended by the study of isotopes. It was early observed that some of the radioactive elements which showed distinct radioactive properties were chemically so alike that it was impossible to effect their separation when mixed together. Similar elements of this kind were called "isotopes" by Soddy, since they appeared to occupy the same place in the periodic table. For example, a number of radioactive elements in the uranium and thorium series have been found to have physical and chemical properties identical with those of ordinary lead, but yet to have atomic weights differing from ordinary lead, and also distinctive radioactive properties. The nuclear theory of the atom offers at once a simple interpretation of the relation between isotopic elements. Since the chemical properties of an element are controlled by its nuclear charge and little influenced by its mass, isotopes must correspond to atoms with the same nuclear charge but of different nuclear mass. Such a view also offers a simple explanation why the radioactive isotopes show different radioactive properties, for it is to be anticipated that the stability of a nucleus will be much influenced by its mass and arrangement.

Our knowledge of isotopes has been widely extended in the last few years by Aston, who has devised an accurate direct method for showing the presence of isotopes in the ordinary elements. He has found that some of the elements are "pure"—*i.e.* consist of atoms of identical mass—while others contain a mixture of two or more isotopes. In the case of the isotopic elements, the atomic mass, as ordinarily measured by the chemist, is a mean value depending on the atomic masses of the individual isotopes and their relative abundance. These investigations have not only shown clearly that the number of distinct species of atoms is much greater than was supposed, but have also brought out a relation between the elements of great interest and importance. The atomic masses of the isotopes of most of the elements examined have been found, to an accuracy of about one in a thousand, to be whole numbers in terms of oxygen, 16. This indicates that the nuclei are ultimately built up of protons of mass very nearly 1 and of electrons. It is natural to suppose that this building unit is the hydrogen nucleus, but that its average mass in the complex nucleus is somewhat less than its mass in the free state owing to the close packing of the charged units in the nuclear structure. We have already seen that the helium nucleus of mass 4 is probably a secondary unit of great importance in the building up of many atoms, and it may be that other simple combinations of protons and electrons of mass 2 and 3 occur in the nucleus, but these have not been observed in the free state.

While the mass of the majority of the isotopes are nearly whole numbers, certain cases have been observed by Aston where this rule is slightly departed from. Such variations in mass may ultimately prove of great importance in throwing light on the arrangement and closeness of packing of the protons and electrons, and for this reason it is to be hoped that it may soon prove possible to compare atomic masses of the elements with much greater precision even than at present.

While we may be confident that the proton and the electron are the ultimate units which take part in the building up of all nuclei, and can deduce with some certainty the number of protons and electrons in the nuclei of all atoms, we have little, if any, information on the distribution of these units in the atom or on the nature of the forces that hold them in equilibrium. While it is known that the law of the inverse square holds for the electrical forces some distance from the nucleus, it seems certain that this law breaks down inside the nucleus. A detailed study of the collisions between α-particles and hydrogen atoms, where the nuclei approach very close to each other, shows that the forces between nuclei increase ultimately much more rapidly than is to be expected from the law of the inverse square, and it may be that new and unexpected forces may come into importance at the very small distances separating the protons and electrons in the nucleus. Until we gain more information on the nature and law of variation of the forces inside the nucleus, further progress on the detailed structure of the nucleus may be difficult. At the same time, there

are still a number of hopeful directions in which an attack may be made on this most difficult of problems. A detailed study of the γ-rays from radioactive bodies may be expected to yield information as to the motion of the electrons inside the nucleus, and it may be, as Ellis has suggested, that quantum laws are operative inside as well as outside the nucleus. From a study of the relative proportions of the elements in the earth's crust, Harkins has shown that elements of even atomic number are much more abundant than elements of odd number, suggesting a marked difference of stability in these two classes of elements. It seems probable that any process of stellar evolution must be intimately connected with the building up of complex nuclei from simpler ones, and its study may thus be expected to throw much light on the evolution of the elements.

The nucleus of a heavy atom is undoubtedly a very complicated system, and in a sense a world of its own, little, if at all, influenced by the ordinary physical and chemical agencies at our command. When we consider the mass of a nucleus compared with its volume it seems certain that its density is many billions of times that of our heaviest element. Yet, if we could form a magnified picture of the nucleus, we should expect that it would show a discontinuous structure, occupied but not filled by the minute building units, the protons and electrons, in ceaseless rapid motion controlled by their mutual forces.

Before leaving this subject it is desirable to say a few words on the important question of the energy relations involved in the formation and disintegration of atomic nuclei, first opened up by the study of radioactivity. For example, it is well known that the total evolution of energy during the complete disintegration of one gram of radium is many millions of times greater than in the complete combustion of an equal weight of coal. It is known that this energy is initially mostly emitted in the kinetic form of swift α- and β-particles, and the energy of motion of these bodies is ultimately converted into heat when they are stopped by matter. Since it is believed that the radioactive elements are analogous in structure to the ordinary inactive elements, the idea naturally arose that the atoms of all the elements contained a similar concentration of energy, which would be available for use if only some simple method could be discovered of promoting and controlling their disintegration. This possibility of obtaining new and cheap sources of energy for practical purposes was naturally an alluring prospect to the lay and scientific man alike. It is quite true that, if we were able to hasten the radioactive processes in uranium and thorium so that the whole cycle of their disintegration could be confined to a few days instead of being spread over thousands of millions of years, these elements would provide very convenient sources of energy on a sufficient scale to be of considerable practical importance. Unfortunately, although many experiments have been tried, there is no evidence that the rate of disintegration of these elements can be altered in the slightest degree by the most powerful laboratory agencies. With increase in our knowledge of atomic structure there has been a gradual change of our point of view on this important question, and there is by no means the same certainty to-day as a decade ago that the atoms of an element contain hidden stores of energy. It may be worth while to spend a few minutes in discussing the reason for this change in outlook. This can best be illustrated by considering an interesting analogy between the transformation of a radioactive nucleus and the changes in the electron arrangement of an ordinary atom. It is now well known that it is possible by means of electron bombardment or by appropriate radiation to excite an atom in such a way that one of its superficial electrons is displaced from its ordinary stable position to another temporarily stable position further removed from the nucleus. This electron in course of time falls back into its old position, and its potential energy is converted into radiation in the process. There is some reason for believing that the electron has a definite average life in the displaced position, and that the chance of its return to its original position is governed by the laws of probability. In some respects an "excited" atom of this kind is thus analogous to a radioactive atom, but of course the energy released in the disintegration of a nucleus is of an entirely different order of magnitude from the energy released by return of the electron in the excited atom. It may be that the elements, uranium and thorium, represent the sole survivals in the earth to-day of types of elements that were common in the long-distant ages, when the atoms now composing the earth were in course of formation. A fraction of the atoms of uranium and thorium formed at that time has survived over the long interval on account of their very slow rate of transformation. It is thus possible to regard these atoms as having not yet completed the cycle of changes which the ordinary atoms have long since passed through, and that the atoms are still in the "excited" state where the nuclear units have not yet arranged themselves in positions of ultimate equilibrium, but still have a surplus of energy which can only be released in the form of the characteristic radiation from active matter. On such a view, the presence of a store of energy ready for release is not a property of all atoms, but only of a special class of atoms like the radioactive atoms which have not yet reached the final state for equilibrium.

It may be urged that the artificial disintegration of certain elements by bombardment with swift α-particles gives definite evidence of a store of energy in some of the ordinary elements, for it is known that a few of the hydrogen nuclei, released from aluminium for example, are expelled with such swiftness that the particle has a greater individual energy than the α-particle which causes their liberation. Unfortunately, it is very difficult to give a definite answer on this point until we know more of the details of this disintegration.

On the other hand, another method of attack on this question has become important during the last few years, based on the comparison of the relative masses of the elements. This new point of view can best be illustrated by a comparison of the atomic masses of hydrogen and helium. As we have seen, it seems very probable that helium is not an ultimate unit in the structure of nuclei, but is a very close combination of four hydrogen nuclei and two electrons. The mass of the helium nucleus, 4·00 in terms of O = 16, is considerably less than the mass, 4·03, of four hydrogen nuclei. On modern views there is believed to be a very

close connexion between mass and energy, and this loss in mass in the synthesis of the helium nucleus from hydrogen nuclei indicates that a large amount of energy in the form of radiation has been released in the building of the helium nucleus from its components. It is easy to calculate from this loss of mass that the energy set free in forming one gram of helium is large even compared with that liberated in the total disintegration of one gram of radium. For example, calculation shows that the energy released in the formation of one pound of helium gas is equivalent to the energy emitted in the complete combustion of about eight thousand tons of pure carbon. It has been suggested by Eddington and Perrin that it is mainly to this source of energy that we must look to maintain the heat emission of the sun and hot stars over long periods of time. Calculations of the loss of heat from the sun show that this synthesis of helium need only take place slowly in order to maintain the present rate of radiation for periods of the order of one thousand million years. It must be acknowledged that these arguments are somewhat speculative in character, for no certain experimental evidence has yet been obtained that helium can be formed from hydrogen.

The evidence of the slow rate of stellar evolution, however, certainly indicates that the synthesis of helium, and perhaps other elements of higher atomic weight, may take place slowly in the interior of hot stars. While in the electric discharge through hydrogen at low pressure we can easily reproduce the conditions of the interior of the hottest star so far as regards the energy of motion of the electrons and hydrogen nuclei, we cannot hope to reproduce that enormous density of radiation which must exist in the interior of a giant star. For this and other reasons it may be very difficult, or even impossible, to produce helium from hydrogen under laboratory conditions.

If this view of the great heat emission in the formation of helium be correct, it is clear that the helium nucleus is the most stable of all nuclei, for an amount of energy corresponding to three or four α-particles would be required to disrupt it into its components. In addition, since the mass of the proton in nuclei is nearly 1·000 instead of its mass 1·0072 in the free state, it follows that much more energy must be put into the atom than will be liberated by its disintegration into its ultimate units. At the same time, if we consider an atom of oxygen, which may be supposed to be built up of four helium nuclei as secondary units, the change of mass, if any, in its synthesis from already formed helium nuclei is so small that we cannot yet be certain whether there will be a gain or loss of energy by its disintegration into helium nuclei, but in any case we are certain that the magnitude of the energy will be much less than for the synthesis of helium from hydrogen. Our information on this subject of energy changes in the formation or disintegration of atoms in general is as yet too uncertain and speculative to give any decided opinion on future possibilities in this direction, but I have endeavoured to outline some of the main arguments which should be taken into account.

I must now bring to an end my survey, I am afraid all too brief and inadequate, of this great period of advance in physical science. In the short time at my disposal it has been impossible for me, even if I had the knowledge, to refer to the great advances made during the period under consideration in all branches of pure and applied science. I am well aware that in some departments the progress made may justly compare with that of my own subject. In these great additions to our knowledge of the structure of matter every civilised nation has taken an active part, but we may be justly proud that Great Britain has made many fundamental contributions. With this country I must properly include the Dominions overseas, for they have not been behindhand in their contributions to this new knowledge. It is, I am sure, a matter of pride to this country that the scientific men of the Dominions have been responsible for some of the most fundamental discoveries of this epoch, particularly in radioactivity.

This tide of advance was continuous from 1896, but there was an inevitable slackening during the War. It is a matter of good omen that, in the last few years, the old rate of progress has not only been maintained but even intensified, and there appears to be no obvious sign that this period of great advances has come to an end. There has never been a time when the enthusiasm of the scientific workers was greater, or when there was a more hopeful feeling that great advances were imminent. This feeling is no doubt in part due to the great improvement during this epoch of the technical methods of attack, for problems that at one time seemed unattackable are now seen to be likely to fall before the new methods. In the main, the epoch under consideration has been an age of experiment, where the experimenter has been the pioneer in the attack on new problems. At the same time, it has been also an age of bold ideas in theory, as the quantum theory and the theory of relativity so well illustrate.

I feel it is a great privilege to have witnessed this period, which may almost be termed the renaissance of physics. It has been of extraordinary intellectual interest to watch the gradual unfolding of new ideas and the ever-changing methods of attack on difficult problems. It has been of great interest, too, to note the comparative simplicity of the ideas that have ultimately emerged. For example, no one could have anticipated that the general relation between the elements would prove to be of so simple a character as we now believe it to be. It is an illustration of the fact that Nature appears to work in a simple way, and that the more fundamental the problem, often the simpler are the conceptions needed for its explanation. The rapidity and certitude of the advance in this epoch have largely depended on the fact that it has been possible to devise experiments so that few variables were involved. For example, the study of the structure of the atom has been much facilitated by the possibility of examining the effects due to a single atom of matter, or, as in radioactivity or X-rays, of studying processes going on in the individual atom which were quite uninfluenced by external conditions.

In watching the rapidity of this tide of advance in physics I have become more and more impressed by the power of the scientific method of extending our knowledge of Nature. Experiment, directed by the disciplined imagination either of an individual, or still better, of a group of individuals of varied mental

outlook, is able to achieve results which far transcend the imagination alone of the greatest natural philosopher. Experiment without imagination, or imagination without recourse to experiment, can accomplish little, but, for effective progress, a happy blend of these two powers is necessary. The unknown appears as a dense mist before the eyes of men. In penetrating this obscurity we cannot invoke the aid of supermen, but must depend on the combined efforts of a number of adequately trained ordinary men of scientific imagination. Each in his own special field of inquiry is enabled by the scientific method to penetrate a short distance, and his work reacts upon and influences the whole body of other workers. From time to time there arises an illuminating conception, based on accumulated knowledge, which lights up a large region and shows the connexion between these individual efforts so that a general advance follows. The attack begins anew on a wider front, and often with improved technical weapons. The conception which led to this advance often appears simple and obvious when once it has been put forward. This is a common experience, and the scientific man often feels a sense of disappointment that he himself had not foreseen a development which ultimately seems so clear and inevitable.

The intellectual interest due to the rapid growth of science to-day cannot fail to act as a stimulus to young men to join in scientific investigation. In every branch of science there are numerous problems of fundamental interest and importance which await solution. We may confidently predict an accelerated rate of progress of scientific discovery, beneficial to mankind certainly in a material, but possibly even more so in an intellectual sense. In order to obtain the best results, certain conditions must, however, be fulfilled. It is necessary that our universities and other specific institutions should be liberally supported, so as not only to be in a position to train adequately young investigators of promise, but also to serve themselves as active centres of research. At the same time there must be a reasonable competence for those who have shown a capacity for original investigation. Not least, peace throughout the civilised world is as important for rapid scientific development as for general commercial prosperity. Indeed, science is truly international, and for progress in many directions the co-operation of nations is as essential as the co-operation of individuals. Science, no less than industry, desires a stability not yet achieved in world conditions.

There is an error far too prevalent to-day that science progresses by the demolition of former well-established theories. Such is very rarely the case. For example, it is often stated that Einstein's general theory of relativity has overthrown the work of Newton on gravitation. No statement could be further from the truth. Their works, in fact, are scarcely comparable, for they deal with different fields of thought. So far as the work of Einstein is relevant to that of Newton, it is simply a generalisation and broadening of its basis; in fact, a typical case of mathematical and physical development. In general, a great principle is not discarded, but so modified that it rests on a broader and more stable basis.

It is clear that the splendid period of scientific activity which we have here reviewed owes much of its success and intellectual appeal to the labours of those great men in the past, who wisely laid the sure foundations on which the scientific worker builds to-day, or to quote from the words inscribed in the dome of the National Gallery, "The works of those who have stood the test of ages have a claim to that respect and veneration to which no modern can pretend."

Scientific Problems and Progress.[1]

SUMMARIES OF ADDRESSES OF PRESIDENTS OF SECTIONS OF THE BRITISH ASSOCIATION.

THE ORIGIN OF SPECTRA.

THE focus of Prof. McLennan's remarks in his presidential address to Section A (Mathematics and Physics), to be delivered on September 17, is Bohr's theory of the origin of radiation and of atomic structure. Evidence in support of the theory is drawn largely from recent researches on the spectra of the elements.

Among the subjects discussed are the significance of the fine structure of the spectral lines of hydrogen and the recent attempts to devise a model of the helium atom capable of accounting for the characteristics of the helium spectrum.

In dealing with the question of the genesis of atoms of various types, illustrations are given of the view recently put forward by Bohr that the fundamental process that must apply consists in the successive binding of electrons by a nucleus originally naked. Bohr's scheme of electronic orbits for the atoms of different elements provides a means of establishing a connexion between spectral series formulæ of different types and the energy levels in atoms and, also, of deducing the values of resonance and ionisation potentials, hitherto undetermined, for a number of elements. Special attention is paid to the elements of the lead-tin and chromium-manganese groups.

A number of illustrations are given of the Kossel-Sommerfeld Displacement Law, and the importance of the recent work of Fowler and of Paschen in this connexion is emphasised. Spectroscopic data, recently obtained, that are likely to lead to extensions of this work are also discussed.

In dealing with the magnetic properties of certain contiguous elements, anomalies are referred to that apparently do not find so ready an explanation with Bohr's scheme of electronic orbits for the atoms of successive elements as the Kossel-Sommerfeld Displacement Law. Reference is also made to the principle of quantisation in space recently brought into prominence by the interesting experiments of Gerlach and Stern and by the work of R. W. Wood and Ellett.

[1] All the presidential addresses are published in full in "The Advancement of Science: 1923" (London: John Murray).

This latter, it will be recalled, deals with the power possessed by weak magnetic fields of modifying the capability shown by the vapours of mercury and sodium of polarising radiation scattered by them.

The adiabatic hypothesis enunciated by Ehrenfest is discussed, and also the use of this principle in conjunction with the quantum theory in elucidating Zeeman effects of the normal type. Reference is made, as well, to the interesting and suggestive attempts of Heisenberg and Sommerfeld to find in a development of the quantum theory an explanation of the anomalous Zeeman effect exhibited by certain classes of spectral lines. In this application of the quantum theory it is assumed that the doublet separations characteristic of series such as those of the arc spectra of the alkali elements are in reality Zeeman separations produced by intra-atomic magnetic fields. In conclusion there are illustrations of the magnitude of such intra-atomic magnetic fields, and a discussion of some of the difficulties raised by Heisenberg and Sommerfeld's theory and of some objections in the way of its immediate and general acceptance.

Physical Chemistry of Surfaces.

The subjects dealt with by Prof. F. G. Donnan, in his address to Section B (Chemistry) are principally molecular orientation and molecular dimensions at surfaces and in surface films, molecular concentration at surfaces and its effect on surface tension, electrical potential differences at surfaces, stabilities of foams, oil suspensions, lyophobic hydrosols, and oil emulsions. The surfaces especially considered are the liquid-gas and liquid-liquid surfaces. The researches of W. B. Hardy have led to the conception of surface layers of oriented molecules, as the result of unsymmetrical fields of force surrounding molecules, due to the presence of active atoms or atomic groups. The views of Hardy have been confirmed by the work of W. D. Harkins and his collaborators.

The study of *unimolecular* surface layers of insoluble substances on the surface of water, initiated by the late Lord Rayleigh and developed by H. Devaux and A. Marcelin, has led in the hands of I. Langmuir and N. K. Adam to the determination of molecular and atomic dimensions. Certain recent investigations by X-ray methods have an interesting bearing on these results.

Unimolecular layers may also be formed by the adsorption of vapours on liquid and solid surfaces. Dissolved substances which lower the surface tension of a gas-liquid or liquid-liquid interface concentrate at these interfaces. Do they form unimolecular layers?

Electric potential differences exist at the gas-liquid, liquid-liquid, and solid-liquid interfaces. These potential differences are affected by "surface-active" substances, by ions, colloidal micelles, etc. The potential differences determine the stabilities of oil suspensions and lyophobic hydrosols. The "critical" potential differences and the "critical zone" of potential difference are of importance in such cases.

The formation of concentrated surface layers and surface films plays an important rôle in the production and stabilisation of emulsions. Surface actions are of importance in biological phenomena. The existence and activity of the living organism are dynamic and depend on an environment which is not in equilibrium. The living organism is an *individual*. Further progress will depend on the study of the particular actions of individuals rather than the average behaviour of "crowds."

Evolutional Palæontology.

The presidential address by Dr. Gertrude Elles to Section C (Geology) is on the subject of "Evolutional Palæontology in Relation to the Lower Palæozoic Rocks." The problems of the Lower Palæozoic Rocks still awaiting solution are in the main those of classification and structure, which are largely interdependent. The most satisfactory solution appears to lie in the application of the principles of evolutional palæontology. The most effective modern classification of strata is that based upon the coming in of new forms of life, but if it is to be of wide application this must not be connected directly with changes in the character of the sedimentation.

The variation in the nature of shallow-water faunas due to various factors such as temperature, salinity, and clearness of the water, is illustrated by reference to the recent work at the Danish Biological Station; the classification and correlation of such deposits must be a matter of great difficulty unless a common principle can be introduced. The standard for purposes of classification must be sought in the faunas of the deeper waters of the Lower Palæozoic seas, where the changes in the fauna show primarily as an advance in the evolutional stage of the organisms concerned. The various shallow-water deposits should be referred to those of deeper-water origin when possible, or the relative ages may to some extent be determined by noting the evolutional stage reached by various organisms composing the faunas.

These principles are illustrated by a study of the evolution of the Graptoloidea as the characteristic fauna of the deeper-water sediments of the Lower Palæozoic, and it is shown that important evolutional stages are characteristic of definite geological horizons, these being recognisable without any knowledge of the various Graptolite species. In the faunas of the shallower-waters the evolution of certain features in some species-groups of the Trilobita are described and the horizons at which these occur are noted. Mention is made of the work already published on other fossil phyla, and attention is especially directed to that of various observers on the evolution of the corals in the Carboniferous as the type of work to be aimed at in the future in the Lower Palæozoic Rocks.

The old purely descriptive work so often carried out entirely in the museum or laboratory must give place to that in which fossils are regarded as parts of once-living entities possessing definite ancestors and descendants developing along definite lines, the relationships of these being controlled always by field work.

Zoology and its Human Aspects.

Prof. Ashworth devoted the first part of his address to Section D (Zoology), on September 13, to a brief retrospective glance over some of the lines of development in zoology since the last meeting in

Liverpool. He referred to the rapid extension of physiological methods of inquiry to the lower organisms, the discovery of artificial parthenogenesis, the intensive study of egg-cleavage, cell-lineage, and the maturation of the egg and sperm, the remarkable progress of cytology, and to researches on the structural basis of heredity and on the nuclear mechanism correlated with sex. Other subjects discussed were the study of the finer structure of the nerve-cell and its processes and of the neuromotor system of the Protozoa, the investigations on the ciliate Protozoa, especially on Paramæcium, with the purpose of ascertaining whether decline and death depend on inherent factors or on external conditions, and the researches on the culture of tissues, which are leading to a knowledge of the conditions which determine the growth and differentiation of somatic cells.

In the second part of the address some of the bearings of zoology on human welfare were considered. At the time of the last meeting in Liverpool insects were suspected of acting as transmitters of certain pathogenic organisms to man, but these cases were few and in no single instance had the life-cycle of the organism been worked out and the mode of transmission from insect to man ascertained. The part played by the mosquito as host and transmitter of the parasite of malaria was made known by Ross nearly two years after that meeting. Of the ten important examples of arthropods now proved to act as carriers of pathogenic organisms to man, Prof. Ashworth chose three for consideration, namely, Stegomyia and yellow fever, tsetse-flies and sleeping-sickness, and the flea *Xenopsylla cheopis* and plague, this last providing a fine illustration of the value of careful work on the systematics and on the structure and bionomics of the insect concerned. Intensive work on the Protozoa has been an outstanding feature during the last twenty-five years, and *Entamœba histolytica*, the organism of amœbic dysentery, was taken as an example of the importance of researches on Protozoa which directly affect man. Of the notable investigations on parasitic worms, reference was made to the great advances in our knowledge of the life-history and bionomics of Ancylostoma and of Schistosoma (Bilharzia), which have enabled effective measures to be taken against infection by these parasites.

In conclusion, Prof. Ashworth referred to the place and value of zoology in the medical curriculum, gave an outline of the subjects which he considered should be included in the course of zoology for medical students, and invited discussion on this part of the address.

The British Empire as a Maritime State.

The subject of Dr. Vaughan Cornish's presidential address to Section E (Geography) is the "Geographical Position of the British Empire." It may be thought that an Empire on which the sun never sets, with lands in both hemispheres and on every continent, cannot be assigned a place upon the map, and in fact so long as it is regarded from the continental point of view it cannot be given a definite geographical position. It is, however, a maritime State, the metropolitan and other provinces being united by ocean routes on which lie British ports of call which can be used as naval stations, but separated strategically by those parts of the ocean which are not so provided, and are readily dominated from the ports of other Great Powers. An examination of these conditions shows that, taking account only of the communications which are available in all circumstances, the lands of the British Empire are connected by the Atlantic and Indian, separated by the North Pacific Ocean. Hence the geographical position of the Empire is well represented by the form of Mercator map in which the meridian of Greenwich is central and the right- and left-hand edges are at longitude 180°. The Empire thus appears astride the North Atlantic and the Indian Ocean, but with its Pacific shores unconnected.

A symmetrical arrangement is revealed upon this map if a direct line (part of a great circle) be drawn from Halifax, Nova Scotia, the eastern terminal of the Canadian Pacific Railway, to Fremantle, the western terminal port of the Australian railways. This direct line (twisted on the map into the form of the letter S) passes through Lower Egypt close to the Suez Canal, which is not very far from its middle point. It follows somewhat closely the main steamship track of the Empire. At one end is Canada, at the other Australasia, the British Isles on the north and South Africa on the south. The coloured populations of the Empire are also distributed symmetrically with reference to the line, those of India on the east, of Africa on the west, so that the great circle from Halifax, N.S., eastwards to Fremantle is the geometrical axis of the Empire.

The Empire as thus mapped can be shown to have an intermediate position on the present commercial and international communications of the world such as no other Great Power occupies, so that the British, in a greater degree than any other people, are the doorkeepers of the world.

The consolidation of the position turns on the future of colonisation during the time which remains before the untilled lands of the world are occupied by peasantry. In the second part of the address the present tendency of this movement is traced both among coloured and white peoples, and special attention is given to the question, now so much debated, whether a surplus of birth-rate over death-rate in Great Britain is, or is not, in the interests of the country, of the peoples of the Empire, and of mankind.

Population and Unemployment.

The common impression that Europe is already threatened with over-population may be traced to two sources—to observation of the exceptional volume of unemployment to-day, and to the words of certain economists describing Europe before the War. Sir William Beveridge deals with these subjects in his presidential address to be given to Section F (Economics) on Monday, September 17. Unemployment does not necessarily or naturally point to excessive growth of population; severe and prolonged unemployment has occurred at times and in countries which were certainly not marked by over-population. Statements such as those of Mr. Keynes, that Europe was over-populated even before the War, appear ill-founded; in Europe, no less than in the New World, the yield of corn

per acre and per head of the population was rising, not falling; the price of corn relatively to other commodities was falling, not rising, up to the eve of War. There is still room for the expansion of the white races. In Britain, as distinct from Europe as a whole, the rate of material progress which marked the Victorian age was not maintained from 1900 to 1910; this apparent check, however, may have been temporary and due to special causes.

In considering the position of Britain after the War, the example of German Austria, a highly specialised and advanced community depending on free trade over a large and varied area, is apposite. The optimum density of population in any given region depends, not on that region alone, but also on the economic conditions and needs of the rest of the world. A decline of international dealing hurts all, but most of all the highly specialised communities typified by German Austria and Britain. The suggestion that we should avoid the "Austrian risk" in future by aiming at self-sufficiency is not practical. Britain, as we know it, and with anything like its present population, depends upon peace and trade. Its excessive unemployment to-day can be fully explained by the War and its aftermath of economic disorganisation, and the remedy must be sought elsewhere than in birth control.

Though, however, increased birth control is not required by the conditions of Europe before the War and is irrelevant to its present troubles, the problem of numbers has to be faced. Man cannot with safety indefinitely reduce the death-rate and leave the birth-rate to look after itself; as a matter of history, he has at almost all stages of his development limited the number of his descendants. The problem of population is, at the moment, a matter for suspension of judgment and inquiry. Two inquiries in particular are suggested: one, into the potential agricultural resources of the world, analogous to the inquiries made at various times as to coal; the other, into the physical, psychological, and social effects of the restriction of fertility which has become general among European races in the past fifty years.

Transport and its Debt to Science.

Sir Henry Fowler's address to Section G (Engineering) deals with the subject of transport and its indebtedness to science. Since its foundation the city of Liverpool has been associated with transport, and no town owes so much to the facilities to trade which transport has afforded, or has played so frequently the part of a pioneer in the inception of new methods. The Mersey and Trent Canal, the Manchester Ship Canal, the Rainhill Railway trials, the electrification of the Liverpool and Southport railway, and the Commercial Motor Trials of the Liverpool Self-Propelled Traffic Association testify to this.

All advances in methods of transport have been the result of the availability of scientific knowledge. Since the time of Watt these advances have taken place when the "ordered knowledge of natural phenomena" has allowed. Progress has depended upon this knowledge; locomotive design benefited by the experiments of Schmidt; electric traction by the numberless researches into electrical phenomena, and the development of the turbine by Parsons: the work of the latter gave a fresh impulse to marine transport. The motor car and the aeroplane owe much to the Otto cycle and the work of Daimler on internal combustion engines. The above are the results of work on methods of propulsion. The advance in our knowledge of material has also played its part. Until the invention of Bessemer the material requisite was not available in quantities sufficient to allow of much progress being made. The early work of Hadfield on alloy steels has developed in such a manner that the motor car and the aeroplane are possible as we have them to-day. It is not alone in general and large questions that scientific knowledge has helped transport, but it can be shown that a careful investigation of the properties of the steel from which locomotive crank axles are made has led to a large increase in their life.

One great trouble with scientific development on industrial lines is the difficulty of obtaining correct results from practical application. The transport bodies have no axe to grind in the use of any particular thing, and should show their appreciation of their indebtedness to science by freely giving the results of their work.

Another trouble which still exists is that the personal contact of the scientific man and the practical engineer does not occur frequently enough, and the meetings of the Association should be more freely used for this purpose.

Egypt as a Field for Anthropological Research.

As the habits, modes of life, and occupations of all communities are immediately dependent upon the features and products of the land in which they dwell, any inquiry into Egyptian origins ought to begin with the question, What were the physical conditions which prevailed in Egypt and its bordering deserts in the period immediately preceding, and during the rise of, the Egyptian civilisation? Discussing what is actually known about the fauna and flora of the dynastic and predynastic periods, Prof. Newberry, in his presidential address to be delivered to Section H (Anthropology) on September 17, shows that a material change must have taken place in the character of the climate of North-Eastern Africa since pre-agricultural days. The fauna and flora have receded southwards, and the physical conditions which now prevail in the region north of the Atbara are similar to those which prevailed in the deserts on either side of the Lower Nile Valley in early times. The people living in this part of the Anglo-Egyptian Sudan are Hamite, and, as Prof. Seligman has shown, the least modified of these people are physically identical with the predynastic Egyptians of Upper Egypt. Prof. Newberry suggests that they, like the fauna and flora, have receded southwards under the pressure of the advance of civilisation, and that the physical conditions of the country have preserved them to a great extent in their primitive life and pursuits. The picture of life in the Taka country as drawn by Burckhardt in 1813 would, except in some unimportant details, equally well depict the predynastic Egyptians.

Prof. Newberry proceeds to show that the earliest

civilisation in Egypt arose in the Delta, and that it spread up the river. Before Menes conquered the north there had been a kingdom of Middle and Upper Egypt, and before that a kingdom with its capital at Sais in the North-Western Delta. The people of the North-Western Delta were closely connected with the early Cretans, and were of the same race as the pre-dynastic people of Upper Egypt. In the Eastern Delta at an early period lived a pastoral clan that had come in from Western Asia and brought into Egypt the domesticated goat and sheep, as well as two important cults connected with trees that were not indigenous to the soil of Egypt. The absence of timber trees makes it doubtful whether the art of the carpenter arose in the Nile Valley. Architectural styles founded on wood construction cannot well have originated in a timberless country, nor could the art of building sailing or sea-going ships. It may be doubted that the custom of burying the dead in wooden coffins arose in Egypt; the resins used in embalming were not native to the Nile Valley. No incense trees or shrubs are known in Egypt, hence it is probable that the ceremonial use of incense did not arise there. Such are some of the anthropological questions raised by a study of the flora of the Lower Nile Valley.

Symbiosis in Animals and Plants.

Prof. George H. F. Nuttall's address to Section I (Physiology) dealt with (1) Symbiosis in plants: lichens; root-nodules of leguminous plants; the significance of micorhiza in various plants, especially orchids; and (2) Symbiosis in animals: Algæ as symbionts in various animals; symbiosis in insects; micro-organisms in relation to luminescence in animals. The subject is one of broad biological interest, an interest that should appeal equally to the physiologist, pathologist, and parasitologist. It is a subject on which much work has been done of recent years, and information relating thereto lies scattered in the scientific literature of different countries.

The term symbiosis denotes a condition of conjoint life existing between different organisms that are benefited to a varying degree by the partnership. The condition of life defined as symbiosis may be regarded as balancing between two extremes, complete immunity and deadly infective disease. Symbiosis has doubtless originated from parasitism. One condition merges into the other, there being no line of demarcation to separate them. Some organisms supposed to be symbionts to-day may prove to be parasites on further investigation. Certain structures that have been described in the past as normal intracellular bodies in animals and plants have in a number of cases been shown to be micro-organisms which can be cultivated or symbionts that are transmissible hereditarily from host to host. The address constitutes a summary of what is known to-day of symbiosis in the animal and vegetable kingdoms. Apart from its scientific interest, the economic importance of studies on symbiosis is exemplified by what has been established, on the botanical side, with regard to the root-nodules of leguminous plants, the germination of orchids, and the origin of tubers.

Mental Differences between Individuals.

The address by Dr. Cyril Burt, president of Section J (Psychology), deals with the mental differences between individuals, with special reference to applied psychology in education and industry. The most remarkable advances made by psychology during recent years consist in the rapid development of what threatens to become a new and separate branch of science; namely, the study of individual differences in mind. The numerous data collected from various fields of applied psychology—from the psychology of education, industry, and war, of mental disorder, deficiency, and crime—are now sufficiently extensive and trustworthy to deserve co-ordination into a single systematic body of knowledge.

Early pseudo-scientific attempts to diagnose mental characteristics from physical and other signs were misled by an inadequate technique. The true procedure was supplied by Sir Francis Galton, who applied to the general problem two special methods of inquiry—the statistical method of correlation, and the experimental method of psychological tests. These in turn rest upon a fundamental assumption, which recent work has verified—the continuity of mental variation. This is the keystone of individual psychology as a science. The differences between one man and another are always a matter of "more or less," seldom, if ever, a question of presence or absence or of "all or none." There are no such things as mental types; there are only mental tendencies.

The general scheme under which individuals are to be studied is much the same, whether they are normal or supernormal, backward, defective, or delinquent, or ordinary applicants for vocational guidance.

The positive foundations for a practical psychology of individual differences have been laid in three broad generalisations, each the separate suggestion of recent experimental work. These consist in a trio of important distinctions: the distinction between intellectual and emotional characteristics, between inborn and acquired mental tendencies, and between general and special capacities. The future progress of individual psychology will consist chiefly in devising more exact methods for examining mental qualities under each of these respective heads.

Aspects of the Study of Botany.

Mr. A. G. Tansley's presidential address to Section K (Botany) deals with some aspects of the development of pure botany during the last thirty or forty years, especially in the British Isles. By means of quotations from representative botanists of the last decade of last century, the views held at that time on the relation of morphology and physiology—that they were two independent "disciplines" or branches of botany—are illustrated. It is pointed out that little progress has been made towards realising the idea of determining the "genealogical tree" of the plant kingdom, and this not so much from the fact that our knowledge is still incomplete, as because, in the recent words of a great authority, it has become evident that the past development of the plant kingdom is represented by

"a series of separate lines, some stretching into a remote past, others of more recent origin," and "it would almost seem that 'missing links' have never existed." The increasing doubt as to whether many organs formerly regarded as homologous are really homologous in the strict sense is mentioned, and it is suggested that our increasing, though still rudimentary, knowledge of the factors that determine organic form will lead us to expect a recurrence of the same formative factors, producing similar structures, on different lines of descent, independently of particular life conditions.

The so-called "Neo-Darwinian" account of evolution is then stated, and its weak points indicated; and a description of the changes brought about by the work of Mendel and his followers, of De Vries and of Johannsen, leads to an attempt to form a picture of the origin of species in the light of present knowledge. It is shown that the problems of phylogenesis and ontogenesis are necessarily interlinked, and it is suggested that in the causal study of development of the individual lies the best hope of determining eventually the real nature of the "genes" which geneticists must postulate to account for the observed phenomena of inheritance.

Emphasis is laid on the view that the central and vital part of biology is, and must be, the study of process, and it is suggested that only by stressing this point of view, especially in elementary teaching, will it be possible to retain the power of looking at the science of plants as a whole and thus of checking the disruptive tendencies which have led to the segregation of different branches of the subject.

The Education of the People.

Prof. T. P. Nunn, in his address to Section L (Educational Science), pointed out that the aim of popular education is to train the young to conserve and develop those elements in the tradition of national life and activity which are consciously judged or instinctively felt to be of most worth. Its content will, therefore, always express the distinctive *ethos* of a nation, and, in particular, will reflect the prevalent view as to the proper relation between the individual and the social body. Assuming that in Great Britain we are committed to the ideal of equal citizenship for all, the ultimate aim of our schools must be to bring all children effectively under the influence of those currents in our cultural tradition which have the greatest and most enduring value. Consideration shows that these must include, in addition to our typical traditions of character and manners, the traditions of creative activity represented in literature, science, and the fundamental arts and crafts. The aim thus indicated cannot be achieved so long as education ends for most boys and girls at fourteen; but it does not necessarily imply a "grammar school curriculum" for all. A technical training, provided that it embodies some dignified tradition of intellectual, aesthetic, or practical activity, satisfies the criterion laid down. It is, however, essential that all education should be liberal in outlook and scope.

Science and the Agricultural Crisis.

The main purpose of the presidential address delivered by Dr. Charles Crowther to Section M (Agriculture) is to indicate some of the directions in which immediate help towards the alleviation of the agricultural crisis can be given by the man of science, and some of the lines along which development of our scientific and educational organisation is more especially necessary at this juncture.

The most fundamental of all kinds of assistance that science can give the farmer is that furnished by way of research, but this must of necessity be slow in development, and dependent for the dissemination of its results throughout the industry upon an extensive and efficient advisory organisation in close touch with the farmer.

Similarly also any raising of the standard of farming through formal education can only be effected gradually, and the conclusion is reached, therefore, that the most hopeful way of rendering assistance quickly is through advisory work. The root difficulty of agricultural educational work in the past has been to secure a sufficiently intimate and widespread contact with the farmer, and for this purpose no agency at our command is so valuable as advisory work, involving as it does a contact with the individual farmer which is both direct and sympathetic, originating indeed in most cases out of a direct request for help.

Rapid progress through advisory work postulates, however, a far more numerous staff of advisers than are available at present, some counties being indeed totally unprovided for, while in many others the advisory staff consists of only one man in the person of the County Agricultural Organiser. It is here where the next extension of facilities should take place. In relation to the organisation operating in direct contact with the farmer, research and organised education are for the time being adequately developed—the latter indeed producing now a considerable surplus of trained men for whom employment in educational work is not available. This in itself implies a certain loss of proportion in the development of the whole agricultural educational organisation, and is to be remedied by the extension of the base upon which the whole structure rests, which is constituted of advice, elementary agricultural education, and propaganda. At the same time a closer degree of co-ordination and co-operation between the various elements of the educational organisation is desirable.

In conclusion, although advisory work may be our most effective means of rendering immediate help, a more permanent contribution to the future prosperity of British agriculture will be made through our educational system in the training of the farmers of the future. As yet we have not succeeded in persuading the general body of farmers that technical education is an essential element in the training of the young farmer. The natural development of such a conviction must perhaps be slow, but might be greatly accelerated if more importance were attached to scientific training as well as practical experience in the letting of farms.

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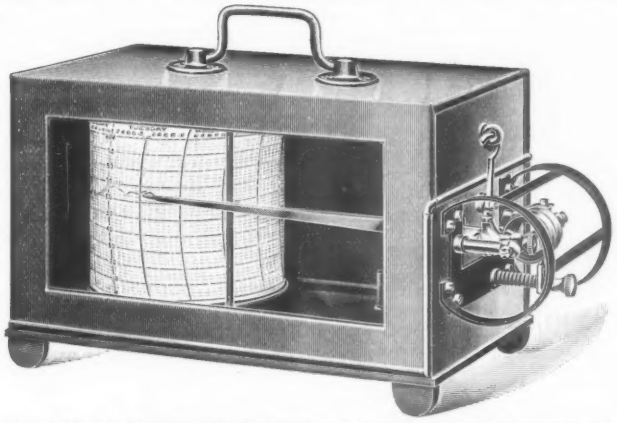

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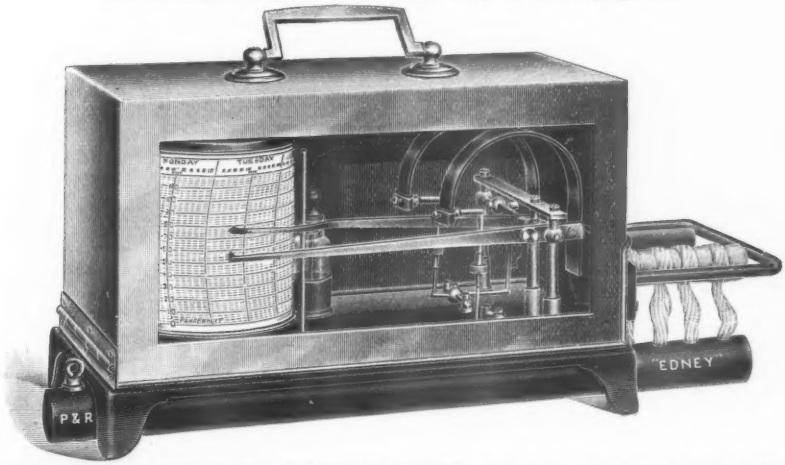

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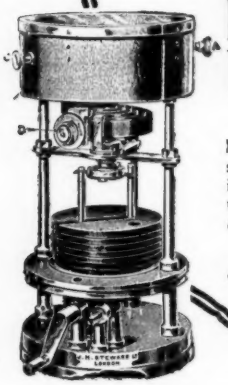

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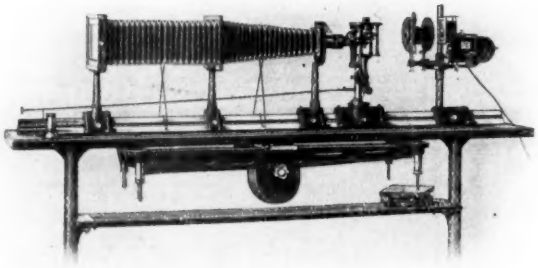

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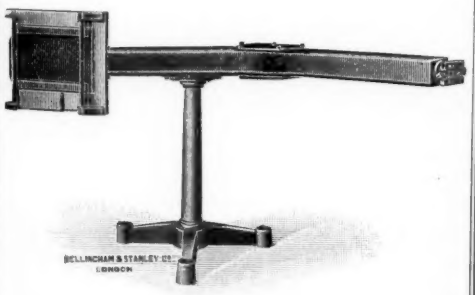

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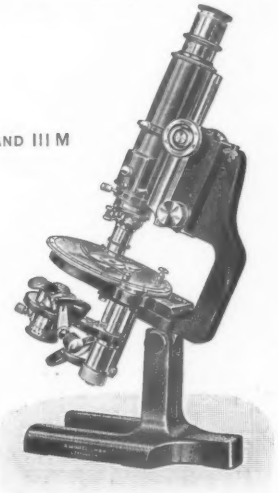

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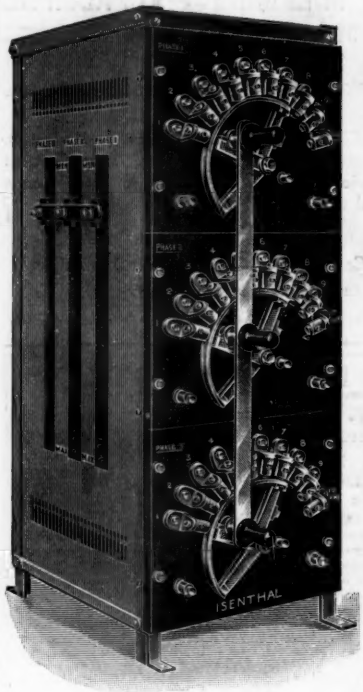

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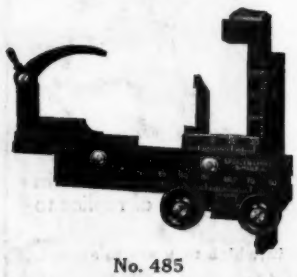

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